EVALUATION OF POST RELEASE LOSSES AND BARGING STRATEGIES THAT MINIMIZE POST RELEASE MORTALITY

DACW68-00-C-0028

Final Report
September, 2005

Carl B. Schreck, Principal Investigator
Mark D. Karnowski, Project Leader
Benjamin J. Clemens, Project Leader

Oregon Cooperative Fish and Wildlife Research Unit
Department of Fisheries and Wildlife
104 Nash Hall
Oregon State University
Corvallis, OR 97331-3803
(541) 737-1961

TABLE OF CONTENTS

EXECUTIVE SUMMARY

Spring/summer Chinook

- Juvenile run-of-river (ROR) spring/summer Chinook migrated to rkm 89 (Stella, WA) more rapidly than their barged (BRG) counterparts from below Bonneville Dam (BON) through the lower Columbia River during 1996-1998. In contrast to BRG fish, most of the variation in migration rate in ROR fish could be explained by flow (KCMS). Differences in migration rates did not translate into differences in estimated survival.

- In 2004, radio-tagged juvenile spring/summer Chinook migrated from the barge release site to the estuary (rkm 46) in 1 – 6 days, compared with 2 – 31 days for acoustic-tagged fish. This variability in migration times could suggest a tagging effect from one of the tags, or it may suggest that one receiver system was more effective at detecting slower fish, or that environmental conditions associated with different release dates randomly affected migration time. Large variations in migration times within a given tag type means that spring/summer Chinook released below Bonneville Dam do not reach the estuary as a distinct group, but rather are distributed over several days.

- CORIE modeling suggests a relationship between water velocity and smolt behavior. The strongest relationship appears to exist during high water velocities ($\geq$ 1 m/s), in which fish and simulated water particle locations correspond, and the fish behavior can be classified as passive. During low water velocities associated with slack tide, the correlation between fish and water were weak and fish behavior was classified as active.

- There were no differences in survival estimates from BON to the upper estuary (rkm 89) between ROR and BRG spring/summer Chinook during 1996-1998. In 2004, there were significant differences in survival estimates between BON and Jim Crow (rkm 46), with radio-tagged fish surviving in greater proportions than acoustic-tagged fish.

- During 1996-1998, 0-40% of all tagged spring/summer Chinook were taken by avian predators compared with 7% in 2004. There were no significant differences in the percentage mortality between BRG and ROR fish for any of these earlier years that were individually examined (1996-1998). There was a significant increase in mortality of BRG spring/summer Chinook during the middle release period in comparison with early and late release periods during 2004.

- Fish condition is a probable variable that affects smolt vulnerability to avian predation. Fish targeted as prey had low Na^+/K^+ ATPase levels and high incidence of BKD infection. These factors should be examined in more detail to verify their role in susceptibility to predation.

Fall Chinook

- ROR and BRG fall Chinook had similar migration rates from BON to rkm 89 (Stella, WA). Large variability in migration rates indicates that fall Chinook do not reach the estuary as a distinct group. However, migration rates within paired releases had no obvious effect on survival estimates to the upper estuary.

- ROR fish survived in higher proportions than their BRG counterparts during all three releases in 2002 and during four of six releases in 2003.

- Overall percentages of fall Chinook detected on piscivorous bird colonies ranged between 0% and 9%. During the low flow year of 2001, mortality estimates of radio-tagged BRG fall Chinook increased steadily throughout the season, whereas ROR fish remained steady at 0%. There were no difference in mortality between BRG or ROR fall Chinook during the higher flow years of 2002 and 2003. It is unknown whether fish condition influenced susceptibility to avian predation.

- Laboratory experiments during 2000-2002 indicated that there were no differences between BRG and ROR fish with respect to numbers infected with BKD, proportion feeding and successfully osmoregulating in saltwater or saltwater preference. In 2001, ROR fish had higher levels of ATPase, suggesting they were more smolted than BRG fish. However, conclusions based on ATPase levels should be considered tenuous. A portion of the BRG fish in one group of the feed intake experiment died, and post-mortem examination revealed that these fish were infested with a flavobacteria of marine origin. If other BRG fish had sublethal infection levels, then it is possible that the pathogen could contribute to delayed mortality once the fish entered saltwater. It is not known why BRG fish were more susceptible to this pathogen than ROR fish.

- Fall Chinook migrating to Lower Granite Dam (LGR) in July-August, during which water temperatures can exceed 70^{o} F, are often of poor quality. This poor quality could be reflected in estuary migration success and subsequent marine survival.

Steelhead

- ROR and BRG steelhead had similar migration speeds between BON and rkm 89 (Stella, WA). Large variations in migration times to the estuary suggest that steelhead do not reach the estuary as a distinct group, but rather are distributed over several days. However, migration rates between BRG and ROR fish released on the same day had no obvious effect on survival estimates to the upper estuary.

- There was no difference in survival between radio-tagged hatchery and wild steelhead to Stella, WA (rkm 89) during 2002-2003. ROR steelhead survived in higher proportions than their BRG counterparts from the release site to Stella during all three release periods in 2002. River flow had a significant, positive effect on survival in this particular year. In contrast to 2002, a higher proportion of BRG steelhead survived in four of six releases (middle to late release periods) in the same stretch of river in 2003.

- There was no difference in survival between radio-tagged hatchery and wild steelhead to Jim Crow point (rkm 46). During 2002, survival estimates for radio-tagged BRG and ROR steelhead between the release site and Jim Crow point varied throughout the season, but there were no differences between BRG and ROR fish on any given release. In 2003, although ROR fish appeared to survive in lower proportions than barged fish during the middle and late portions of the run, these trends were not significant. Release day, however, did have a significant effect on survival during 2002 and 2003.

- During 2001, 6% of BRG steelhead and 1% of ROR steelhead were detected on piscivorous bird colonies. Daily river outflows from Bonneville during the study period for this year averaged 4.07 (0.13) KCMS. During 2002, 11% of BRG fish and 17% of ROR fish were detected on piscivorous bird colonies. Daily river outflows from Bonneville during the study period for 2002 averaged 7.05 (0.22) KCMS. During 2003, 30% of BRG fish and 22% of ROR fish were detected on piscivorous bird colonies. Daily river outflows from Bonneville during the study period for 2003 averaged 7.83 (0.20) KCMS.

- There was no difference in the proportions of hatchery or wild steelhead taken by birds during 2001-2003. There were no differences between the proportions of BRG or ROR steelhead taken by avian predators during 2001-2003.

- Acoustic tag data revealed that steelhead using the WA channel rather than other channels had the lowest survival in the area between the Astoria Bridge and the ocean. Low survival of fish using the WA channel may be related to the close proximity of this migration route to the piscivorous bird colonies on East Sand Island.

- During the early outmigration, BRG steelhead have been shown to have low ATPase levels in relation to ROR fish, suggesting BRG fish may not be physiologically ready to move into full-strength saltwater. However, conclusions based on ATPase levels should be considered tenuous. Lab experiments comparing ROR and BRG fish indicated no differences in the proportion of fish infected with BKD, selecting saltwater, actively consuming food, or successfully osmoregulating.

Recommendations

- Data on migration patterns, numbers taken by piscivorous birds, and physiological data suggest that spring/summer Chinook and steelhead may be the best candidates for alternative barge release strategies. These strategies could be the most beneficial during the mid-late portion of the outmigration.
- We recommend testing alternative transportation release strategies consisting of releasing fish lower in the estuary and coupling release location with tidal stage and time of day.
- We recommend evaluation of a strategy consisting of the potential beneficial effects of not transporting early run fish.
- Given that there are differences in fish quality across the runs of spring/summer Chinook, fall Chinook, and steelhead, we recommend development of a monitoring protocol at Snake River Dams that would allow judging of fitness for migration and marine survival under various environmental scenarios (e.g., elevated temperature towards the latter part of the run). This information could be used to make decisions about the proportion of fish that could be transported.

OBJECTIVES

The goal of this study was to obtain information that can be used to develop and implement transportation strategies that will increase the post release survival of transported fish. To achieve this we investigated spatial and temporal behavior as it relates to survival of transported and run-of-river juvenile yearling (spring/summer) Chinook and other salmonids in the estuarine and near-shore ocean environment. When combined with knowledge of how the physical environment of the estuary (flow, tides) influences migration routes and timing, this information should enable managers to adaptively manage releases of barged fish to increase survival. Specific objectives of the 2004 project were to:

Objective 1 – *Evaluate the post release survival, behavior, habitat use, and migration characteristics of juvenile yearling salmon through the estuary and near shore environment to allow conclusions relevant to barging strategies that could increase survival by affecting rates of emigration and timing of estuarine passage.*

> *1) Document the spatial/temporal migration patterns of transported salmon into and through the estuarine environment.*
>
> *2) Document the mortality of transported salmon migrants and evaluate the effects of migration route on survival.*
>
> *3) Determine how the physical environment of the estuary relates to the movement of outmigrating transported Chinook and develop a model for timing barge releases to minimize mortality in the estuary.*

Objective 2 – *Provide a comprehensive report of all work performed from 1996-2004. This document should provide the rationale for the modification of barging strategies, meant to increase the post release survival of juvenile salmonids. The researchers will provide a number of reasonable alternatives to releasing fish at the current release location based on all of the study year's results as applicable.*

INTRODUCTION

The success of transporting juvenile salmonids around hydroelectric facilities in the Federal Columbia River Power System (FCRPS) is determined in part by performance of fish following release. Fish quality (physiological state) can be determined by stressors experienced during collection, transportation, and release activities. These stressors can have cumulative effects that are manifested in eventual performance (resumption of feeding, survival) after release (Budy et al. 2002). Fish condition at collection facilities can be extremely variable over the course of the run, and among individuals collected at any one time (Giorgi et al. 1988, Dickhoff et al. 1995, Beckman et al. 2000). We hypothesize that variation in fish quality, as a function of passage history, is reflected in the ability of juvenile salmonids to avoid predation and migrate through the lower Columbia River and estuary. Furthermore, fish quality could be affected to varying extents (positive or negative) by a given passage history throughout the season.

Our past research on fall Chinook (*Oncorhynchus tshawytscha*) has indicated that success of fish barging (measured in terms of smolt detection percentages at fixed radio telemetry sites below Bonneville Dam) may be influenced by *when* fish are barged within the smolt migration season (Schreck et al. 2002*a*, 2003*b*). For example, fish migrating near the tails or peak of a run may contain a different percentage of healthier individuals, possibly resulting in intra-seasonal differences in barging success.

Fish health and smoltification have been shown to influence the behavior and short-term survival of juvenile salmonids. For example, stressed and diseased spring Chinook have been shown to delay entry into saltwater when given the opportunity, possibly making them more vulnerable to avian predators (Seals-Price and Schreck 2003*a*). In a general sense, factors that increase exposure of smolts to avian predators such as surface orientation (Birtwell and Kruzynski 1989), lingering in specific areas, due to asynchrony with the tidal cycle (Schreck et al. 2003*a*), or lethargy induced by stress could increase predation risk (Jarvi 1989, Seals-Price and Schreck 2003*a*).

From 1996-1998, as much as 30% of our radio-tagged juvenile spring/summer Chinook salmon during a single release were taken by piscivorous birds (Schreck et al. 1996 and 1997; Schreck and Stahl 1998). Predations on Columbia/Snake River smolts by piscivorous birds could have significant impacts on salmonid populations. Fish consumed by avian predators may be more vulnerable because of cumulative stressors incurred by migration history (barged or Run-of-River), choice of migratory route in the lower estuary, or timing of entry into the estuary, relative to the tidal cycle. Timing to the tidal cycle could mean that fish would reside in the estuary for a prolonged period of time if they enter the estuary during an incoming tide. Prolonged residence in the estuary could mean that fish are exposed to avian predators for a longer period of time.

During the 2004 field season, we collected data on the migration behavior of juvenile spring/summer Chinook salmon in the Lower Columbia River and estuary. The primary objective was to assess migration behavior and patterns, and to estimate survival to the Columbia River estuary for barged juvenile spring/summer Chinook. To achieve this objective, we used acoustic- and radiotelemetry. The second objective was to synthesize our past research on barged (BRG) and Run-of-River (ROR) spring/summer Chinook during 1996-1998 (Schreck et al. 1996 and 1997; Schreck and Stahl 1998) and on fall Chinook and steelhead (*O. mykiss*) during 2000-2003 (Schreck et al. 2000, 2001*a*, 2001*b*, 2001*c*, 2002*a,* 2002*b*, 2003*a*, and 2003*b*) in order to provide suggestions for reasonable alternative transportation release strategies designed to improve survival of juvenile salmonid emigrants in the Columbia River estuary. In these past years, our telemetry research focused on assessing migration patterns and rates and estimating survival and monitoring losses to avian predators, all of which we repeated in 2004 for spring/summer Chinook. Relative fish condition and behavior experiments were also conducted in earlier years, including stress levels (cortisol titres), and ability to osmoregulate (plasma and muscle ion concentrations, ATPase activities, and saltwater preference experiments). The propensity to feed and the existence of Bacterial Kidney Disease (*Renibacterium salmoninarum*) were also assessed. Telemetry and fish condition/behavior experiments were designed to distinguish whether ROR fish fared better or worse than BRG fish.

METHODS

The migratory behavior and survival of hatchery juvenile yearling Chinook (spring Chinook) in the lower Columbia River downstream of Bonneville Dam (BON) was evaluated using both radio and acoustic telemetry. We used digitally encoded radio transmitters and coded acoustic transmitters (Figures 1 and 2; Table 1). The numbers of fish tagged on each date are given in Table 2. Only barged fish were tagged in 2004, unlike 1996-1998, and 2000-2003 (Tables 3 and 4). Tags were surgically implanted into the body cavity of fish in 2004, similar to 2001-2003, whereas gastric implantation was used in previous years (Table 4) (Schreck et al. 1996 and 1997; Schreck and Stahl 1998; Schreck et al. 2001*a*, 2001*b*, 2002*a*, 2002*b*, 2003*a*, 2003*b*).

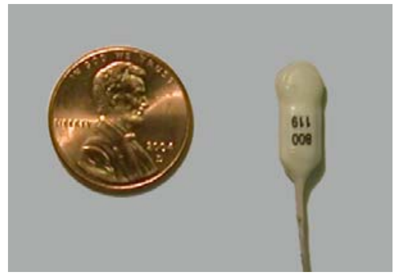


Figure 1. Photograph of the radio transmitter used in the 2004 study

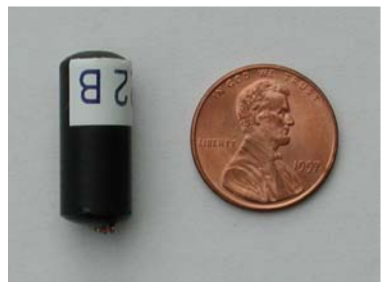


Figure 2. Photograph of the acoustic transmitter used in the 2004 study

Table 1. Telemetry tag specifications for tags used in 2004.

	NTC-3-1 NanoTag®	V8SC-6L
Manufacturer	Lotek Wireless, Inc.	Vemco, Ltd.
Tag type	Radio	Acoustic
Frequency	149-150 mHz	69 KHz
Weight in air (g)	0.85	3.3
Weight in water (g)	0.5	2
Dimensions (L x W x H) (mm)	14.5 x 6.3 x 4.5	20 x 9
Antenna Length (mm)	200[a]	N/A
Burst/pulse interval (secs)	2.9-3.1	6-18
battery life (days)	11-14[b]	~30

[a] Antenna length trimmed down from length of 300 mm.
[b] Although "typical" battery life is 14 days, the warranty life of the tag is 11 days

In order to obtain the highest proportion of Snake River fish for tagging, the timing of tagging and release was scheduled to coincide with peak passage of fish past BON. Since ROR fish were not tagged in 2004, tagging dates related to yearly passage at Lower Granite Dam are shown in Figure 3. The releases of fish in 2004 consisted of three release periods, constituting the early, middle, and late periods of juvenile outmigrations (Figure 3). Within each release period fish were released once per day over the course of four consecutive days. Acoustic-tagged fish were released on the first two days and radio-tagged fish were released on the next two days of each release period (Table 2).

Fish Handling in 2004

Transported (barged) fish were collected from two sources at Lower Granite Dam Juvenile Fish Facility (LGR JFF); either from the NOAA Fisheries (NMFS) PIT-tagging sample, in which fish were collected passively through the separator over the previous 24 h or directly from the separator via dip-netting, as in previous years (Schreck et al. 2002*a*, 2002*b*, 2003*a*, 2003*b*). Fish collection from the separator was somewhat subjective, and therefore non-random. This type of sampling was done to minimize bycatch and to collect individuals that would be large enough to hold a tag.

Spring/summer Chinook abundance on the separator was substantially lower during fish collection for the last four release groups; therefore, we utilized fish from the NMFS sample to meet our tagging quota. All fish captured on the separator were immediately tagged. Fish obtained from the NMFS sample were tagged in the same manner but were held over night in concrete raceways prior to tagging the following day.

Table 2. Summary of release data for barged spring/summer Chinook that were tagged at the Lower Granite (LGR) juvenile collection facilities and released below Bonneville Dam in 2004. N values are the number of tagged fish released; "NOAA Fisheries N" represents the number of fish collected from the NOAA Fisheries sample (included in Total N). Note that the three "clusters" represent different periods of the run (see Figure 3).

Site	**Tag Type**	**Total *N***	**NOAA Fisheries *N***	**Tagging Date**	**Release Date**	**Release Time**	**Release RKM**
LGR	Acoustic	114	0	30-April	3-May	2:50	224-225.6
LGR	Acoustic	164	0	1-May	4-May	4:35	222.4-224
LGR	Radio	99	0	2-May	5-May	3:20	219.2
LGR	Radio	101	0	3-May	6-May	3:35	220.8-222.4
LGR	Acoustic	141	0	14-May	16-May	18:55	220.8
LGR	Acoustic	132	0	15-May	18-May	5:00	220.8-222.4
LGR	Radio	100	0	16-May	19-May	6:30	224-225.6
LGR	Radio	99	0	17-May	20-May	5:20	222.4-224
LGR	Acoustic	102	52	25-May	28-May	5:05	222.4-224
LGR	Acoustic	110	39	26-May	29-May	5:20	220.8
LGR	Radio	97	52	27-May	30-May	5:30	220.8-222.4
LGR	Radio	98	56	28-May	30-May	23:45	224-225.6

Table 3. Specifications on source of fish and numbers released for acoustic-tagged fish. Surgical tag implantations followed a modified method of Moore et al. (1990). Fish collected from the Lower Granite Juvenile Fish Facility (LGR JFF) were collected via dip nets from the separator. During 2002-2004, a portion of the fish were collected from the NOAA Fisheries PIT tag sample. ROR fish collected from the Bonneville Juvenile Fish Facility (BON JFF) were collected from the juvenile smolt monitoring samples and bypass flume.

Year	Species	Origin	Collection Site	Type	# of Releases	# Fish/Release
2004 [a]	spring/summer Chinook	H	LGR JFF	BRG	6 [b]	102-164 [c]
2003 [a]	Steelhead	H	LGR JFF	BRG	6 [b]	39-71 [d]
	Steelhead	W	LGR JFF	BRG	6 [b]	0-48 [e,f]
	Steelhead	H	BON JFF	ROR	6 [b]	9-47
2002 [a]	Steelhead	H	LGR JFF	BRG	3	45-145
	Steelhead	H	BON JFF	ROR	3	40-139 [g]
2001 [a]	Steelhead	H	barges [h]	BRG	2	49-54
	Steelhead	H	BON JFF	ROR	2	45-50

[a] Fish from these years were used for survival estimates with the SURPH model.

[b] Releases were in three "clusters" (i.e. two releases one day apart, occurring three times throughout the season).

[c] Fifty-two and 39 fish were collected from the NOAA Fisheries sample during releases 5 and 6, respectively.

[d] Twenty-eight, 49, and 52 fish were collected from the NOAA Fisheries sample during releases 2, 3, and 4, respectively.

[e] Forty-eight fish were collected from the NOAA Fisheries sample during release 4.

[f] By release, the number of fish were: 1, 9, 0, 48, 23, and 25.

[g] Thirty-five fish were collected from the NOAA Fisheries sample during release 3.

[h] Barged fish were collected and tagged upstream from BON.

Table 4. Specifications on the source of fish, method of tagging, and numbers of radio-tagged fish released for all years of the study. More detailed specifications can be found for the corresponding year in the Schreck et al. (1996-1997, 2000-2003) and Schreck and Stahl (1998) reports. Surgical tag implantations followed a modified method of Moore et al. (1990), and gastric implantations followed the protocol set forth by Ward and Miller (1989). Fish from the Lower Granite Juvenile Fish Facility (LGR JFF) and McNary (MCN) JFF were collected from the separator via dip nets. During 2002-2004, a portion of the fish were collected from the NOAA Fisheries PIT tag sample at LGR JFF. ROR fish collected from the Bonneville (BON) JFF were collected from the juvenile smolt monitoring samples or bypass flume. Species of fish include spring/summer (sp) Chinook, fall (fl) Chinook, and steelhead. Fish origins include hatchery (H), wild (W), and unknown (U).

Year	Species	Origin	Collection Site	Type	Tag Method	# of Releases	# of Fish/Release
2004 [a, b]	sp Chinook	H	LGR JFF	BRG	Surgical	6 [c]	97-101 [d]
2003 [a, b]	fl Chinook	U	LGR JFF	BRG	Surgical	6 [c]	30-61 [e]
	fl Chinook	U	BON JFF	ROR	Surgical	6 [c]	38-50
	Steelhead	H	LGR JFF	BRG	Surgical	6 [c]	47-91 [f]
	Steelhead	W	LGR JFF	BRG	Surgical	6 [c]	29-47 [g]
	Steelhead	H	BON JFF	ROR	Surgical	6 [c]	37-47
2002 [a, b]	fl Chinook	U	Barges [h]	BRG	Surgical	3	31-41
	fl Chinook	U	BON JFF	ROR	Surgical	3	40-43
	Steelhead	H	MCN JFF	BRG	Surgical	3	29-43 [i] (15-34)
	Steelhead	H	Barges [h]	BRG	Surgical	3	40 [i] (16-34)
	Steelhead	W	Barges [h]	BRG	Surgical	3	38-40 [i] (14-31)
	Steelhead	H	BON JFF	ROR	Surgical	3	35-40 [i] (14-39)
2001 [j]	fl Chinook	U	Barges [h]	BRG	Surgical	3	10-24
	fl Chinook	U	BON JFF	ROR	Surgical	3	20-32
	Steelhead	H	Barges [h]	BRG	Surgical	4	15-22
	Steelhead	W	Barges [h]	BRG	Surgical	4	10-15
	Steelhead	H	BON JFF	ROR	Surgical	4	15-24
2000	fl Chinook	U	Barges [h]	BRG	Gastric	1	20
	fl Chinook	U	BON JFF	ROR	Gastric	2	20-22
	Steelhead [k]	H	Barges [h]	BRG	Gastric	4	18-20
	Steelhead [k]	U	BON JFF	ROR	Gastric	4	5-20
1998	sp Chinook [l]	H	LGR JFF	BRG	Gastric	10	14-26
	sp Chinook [l]	U	BON JFF	ROR	Gastric	6	15-25
1997	sp Chinook	H	LGR JFF	BRG	Gastric	6	30-39
	sp Chinook	U	BON JFF	ROR	Gastric	3	30-34
1996	sp Chinook	H	Barges [h]	BRG	Gastric	6	35-39
	sp Chinook	U	BON JFF	ROR	Gastric	4	12-38

[a] Fish from these years were used for survival estimates with the SURPH model.

[b] Used Lotek nanotags (0.85 g) during 2002-2004.

[c] Releases were in three "clusters" (i.e. two releases one day apart, three times throughout the season).

[d] Fifty-two and 56 fish were collected from the NOAA Fisheries sample during releases 5 and 6, respectively.

[e] Thirty and 60 fish were collected from the NOAA Fisheries sample during releases 1 and 2, respectively.

[f] Forty-four, 33, and 47 fish were collected from the NOAA Fisheries sample during releases 1, 2, and 3, respectively.

Table 4. (Continued).

[g] Forty-four and 47 fish were collected from the NOAA Fisheries sample during releases 3 and 4, respectively.
[h] Barged fish were collected and tagged on barges upstream from BON.
[i] The effective sample size was reduced (shown in parentheses) because of duplicate tags.
[j] Switched from ATS beeper tags (1.2 g) to digitally encoded Lotek nanotags (1.4 g or 0.85 g).
[k] One to two fish from each release were implanted with radio depth tags (1.9 g).
[l] Four to six fish on six of the releases were implanted with radio depth tags (1.9 g).

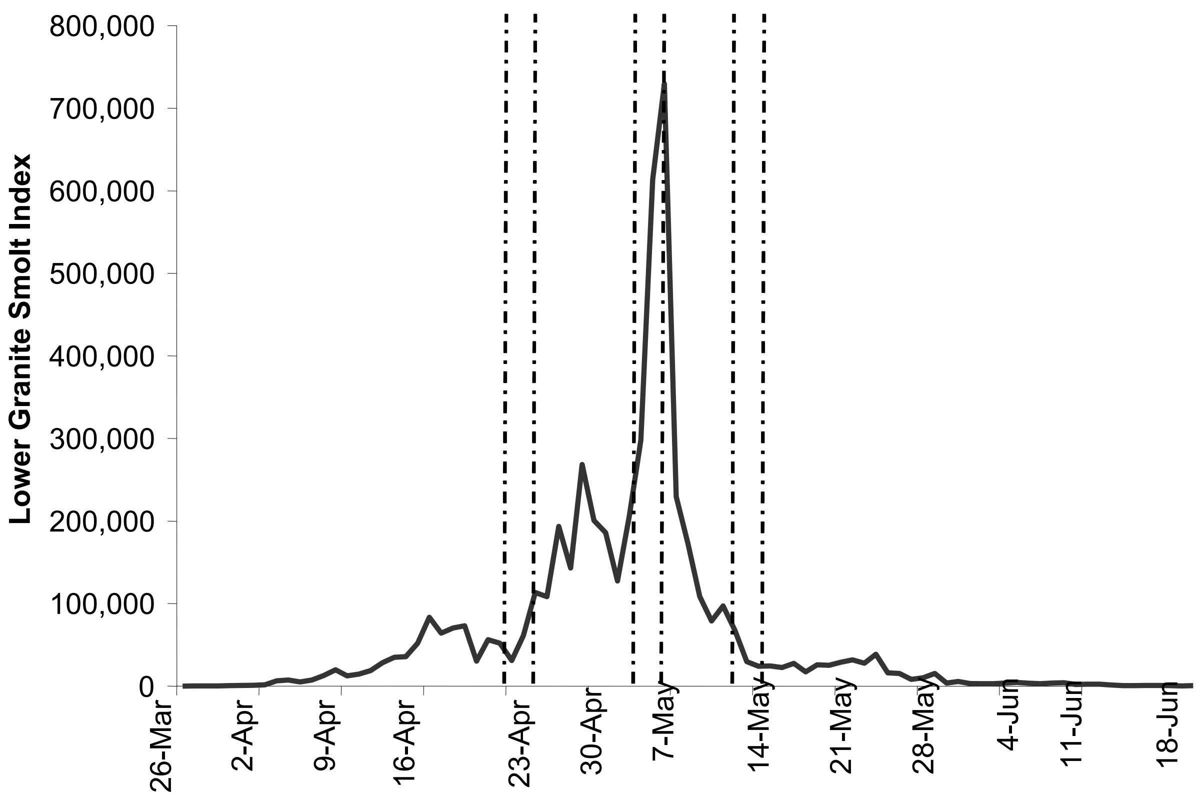


Figure 3. Daily smolt passage estimates (index) at Lower Granite Dam in 2004 for spring/summer Chinook. Dashed vertical lines indicate the first tagging date for each of the three clusters of releases. Smolt numbers were obtained at http://www.cqs.washington.edu/dart/pass_com.html.

Tag Implantation in 2004

Four individuals were trained to surgically implant telemetry tags in juvenile salmon. Their training regimen consisted of one day of instruction and practice tagging of inanimate objects, followed by four days of supervised practicing on live hatchery Chinook at Oregon State University's (OSU) Fish Performance and Genetics Laboratory. The trained individuals surgically implanted telemetry tags into smolts from the Bonneville fish hatchery during a fifth day of practice tagging. These conditions were similar to those experienced at the LGR JFF during the study period. Inspection of sutures and autopsies were conducted on all practice fish to ensure 1) sutures were tight, 2) the incision was closed with no bunching of tissue adjacent to the incision, and 3) no apparent internal hemorrhaging was evident from the tag insertion. All individuals were deemed proficient at surgical tag implantation in smolts. To protect against individual tagging effects, all four individuals were circulated through the tagging position such that all taggers had equal opportunities to tag fish once each tagging day.

Fish to be tagged were immediately placed in covered 5-gallon buckets containing 50 mg/L tricaine methanesulfonate (MS-222) buffered with 125 mg/l $NaHCO_3$ to counteract the acid nature of the anesthetic. Fork length (mm) and weight (g) were measured for each fish, and the transmitter was surgically implanted into the body cavity using a modified technique from Moore et al. (1990). Fish were placed ventral side up on a wetted foam insert to hold them in place. Commercially available Stresscoat®[1] was applied liberally to the surface of the foam insert several times throughout the tagging operation to minimize mucus and scale loss. A 50% solution of anesthetic was perfused over the gills using a squeeze bottle to maintain oxygen to the gills while keeping the fish sedated. A 1 – 1.5 cm incision was made into the ventral body wall anterior to the pelvic girdle. The length of the incision was dictated by the type of tag. Radio tags are relatively small and required a 1.0 cm incision whereas the larger acoustic tags required a 1.5 cm incision. The tag was inserted and the incision closed with sutures (Radio: two sutures, Acoustic: three sutures).

[1] Reference to trade names does not constitute endorsement by OSU or the U.S. Army Corps of Engineers.

Braided vicryl 5-0 sutures were used for suturing spring/summer Chinook. Prior to closing the incision wound a needle encasing the wire antennae was guided through the incision and pushed through the body wall, posterior to the incision and anterior to the pelvic girdle. The orifice created by the antenna exit was treated with fast-drying glue, to minimize antenna movement at the orifice. Preliminary trials at the OSU Fish Performance and Genetics Laboratory indicated that this method was most effective at minimizing tissue damage and fin abrasion around the antenna exit.

The acoustic tags weighed 11.8% and the radio tags 3.0% of the weight of the smallest fish we tagged (28.0 g). By release group, tag weight ranged from 7.4-10.2% of the body weight of the fish for acoustic tags, and 1.9-2.6% for radio tags (Table 1). Previous research (Brown et al. 1999) demonstrated that fish can be implanted with tags up to 12% of the body weight without adverse effects on swimming performance. The current study was within these limits. Jepsen et al. (*in press*) suggested that the criteria for tag-to-body weight ratios are relative to the objectives of the study.

Recovery from Tag Implantation in 2004

Tagged fish were placed in one of two large (approximately 1,000 L) flow-through containers constructed specifically for the purpose of housing fish. These containers, known colloquially by NOAA Fisheries personnel as "Achord tanks", were placed on the barge loading dock and charged with a continual supply of water from the LGR Juvenile Fish Facility (JFF). Temperature was monitored to ensure that water temperature for each holding tank was equivalent to that of the JFF. Temperatures in the JFF and holding tanks varied throughout the study period from 52 ^{o}F and 55 ^{o}F on May 16 and May 27, respectively. Netting was stretched over the top of each tank to prevent fish from leaping free of the enclosure. Care was taken to ensure adequate space above the water surface so that tagged fish were able to gulp air to replenish their swim bladder. Particle board was placed over approximately 80% of the each tank to give the fish respite from the sun. Once half of the tagging quota for the day was met, the particle board was removed and the lid to the tank closed. The second tank was then stocked with the remaining tagged fish.

Fish were released onto the transportation barges on the day following tagging via direct-loading, which consisted of a large hose that was attached to the outlet of each Achord tank. This allowed the fish 12 or more hours to recover from the tagging procedure prior to release on the barge. The water level was slowly drained, and the remaining few fish within each tank were gently coerced into the hose with an aquarium net. Overall tagging mortality was low: 1.9% of tagged fish died and removed from the holding tanks. This mortality appears to have been associated with the quality of fish collected at the dam (i.e., fish that were in poor condition upon capture and prior to tagging tended to exhibit tagging mortality 12 hours after tagging). Tangling of radio wires amongst the fish was not a problem, and no mortalities were observed by any of the barge riders during the barge trip.

Monitoring in 2004

Radiotelemetry:

The progress of radio-tagged individuals was evaluated with a number of fixed monitoring stations in the lower Columbia River and estuary. The most upstream site (transition site) was located near river kilometer (rkm) 89, close to Stella, Washington. This area represents a transition zone between upriver fluvial characteristics and downstream estuarine influences (see Simenstad et al. 1990 for naming conventions of the Columbia River Estuary Data Development Program-CREDDP). The site location is approximately 38 rkm above the maximum extent of saltwater intrusion during low flows (Simenstad et al. 1990), and approximately 144 rkm downstream of BON. In this region the river is relatively narrow and the shipping channel abuts a series of cliffs on the Washington shoreline. Three Yagi-type antenna (4-, 6-, and 9-element) systems were placed on separate masts approximately 3 m above the ground and 31 m above river level. One 9-element antenna pointed directly across the river, one 4-element pointed downward over the cliff, and the stacked 6-element antennae (two individual 6-element antenna, combined using a stacking harness to increase range) pointed across but slightly downriver. Together these antennas provided adequate coverage of the main channel, with detection probabilities ranging from 92-100% during the course of the study in 2004 (Appendix 1, Table

6). Antennas were connected to a Lotek SRX-400 receiver (W32 firmware). This system operated continuously throughout the season, and was powered by 12-volt deep cycle batteries, charged by a solar panel (Siemens ST-40, 40 watt, 2.29 amps). The receiver, batteries, and switch boxes were housed in a weatherproof aluminum box. To avoid accidental data loss, receivers were downloaded prior to each release, during each release, and 4 – 5 days after each release. This provided temporal coverage over the life of the activated tags. Receivers and power systems at other sites were similar to that described here. A total of 10 fixed antenna-receiver systems were placed in the lower river and upper estuary, in order to provide information on passage route, movement in relation to tides, and survival within the lower river. The locations and antenna configurations of each site for 2004 are outlined in Figures 4 and 5. General locations of receiver arrays for previous years are detailed in Table 5.

Figure 4. Maps of the lower Columbia River. The block arrow in the inset map of the lower Columbia River is depicted in the enlarged view to show the locations of the automated radio receiver stations in 2004. Dots denote the locations of fixed automated radio sites. The antenna configuration and the river kilometer are indicated near site locations.

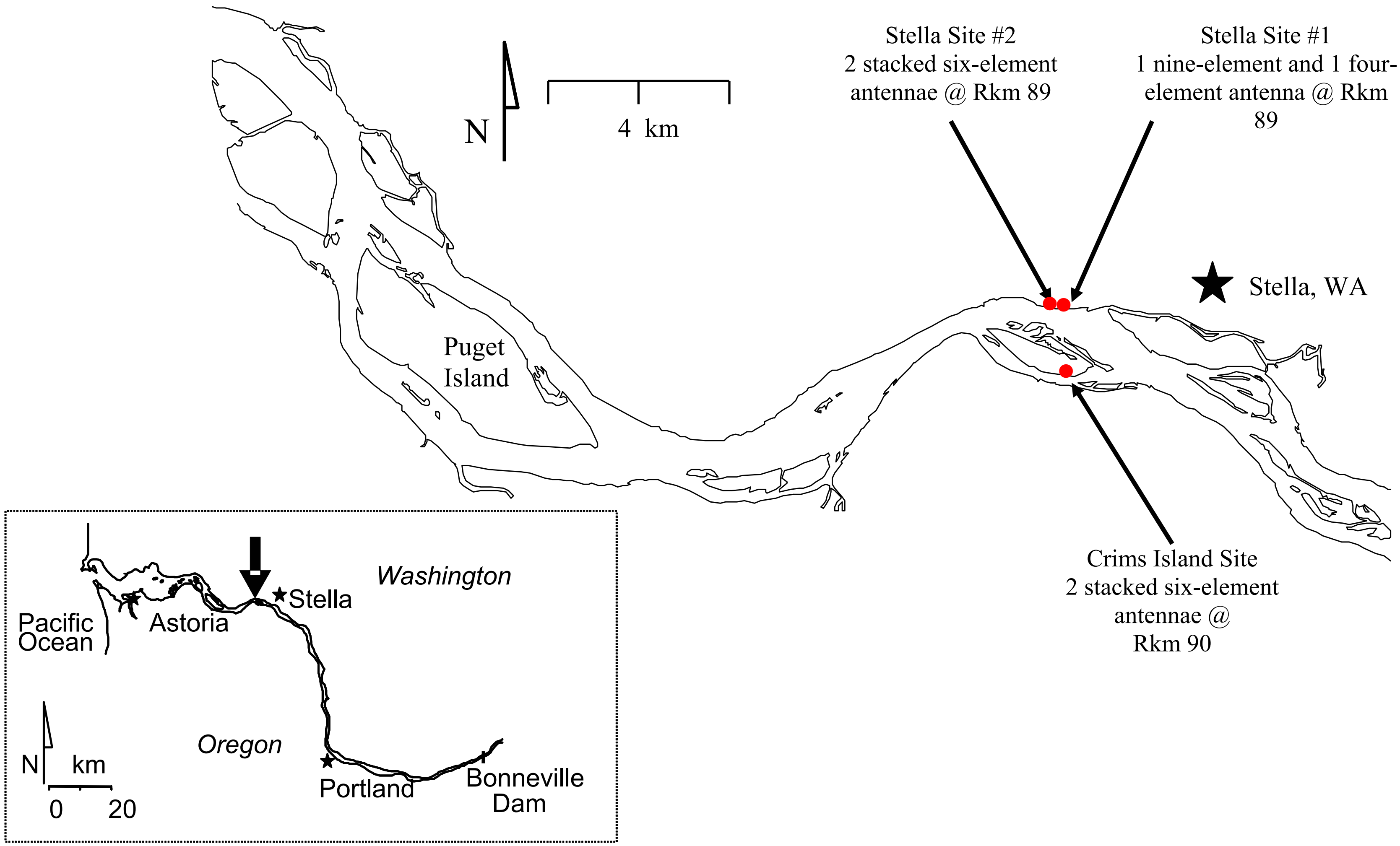


Figure 5. Maps of the Columbia River estuary. The block arrows in the inset map of the Columbia River are depicted in the enlarged view to show the locations of the automated radio receiver stations in 2004. Dots denote the locations of fixed automated radio sites. The antenna configuration and the river kilometer are indicated near site locations.

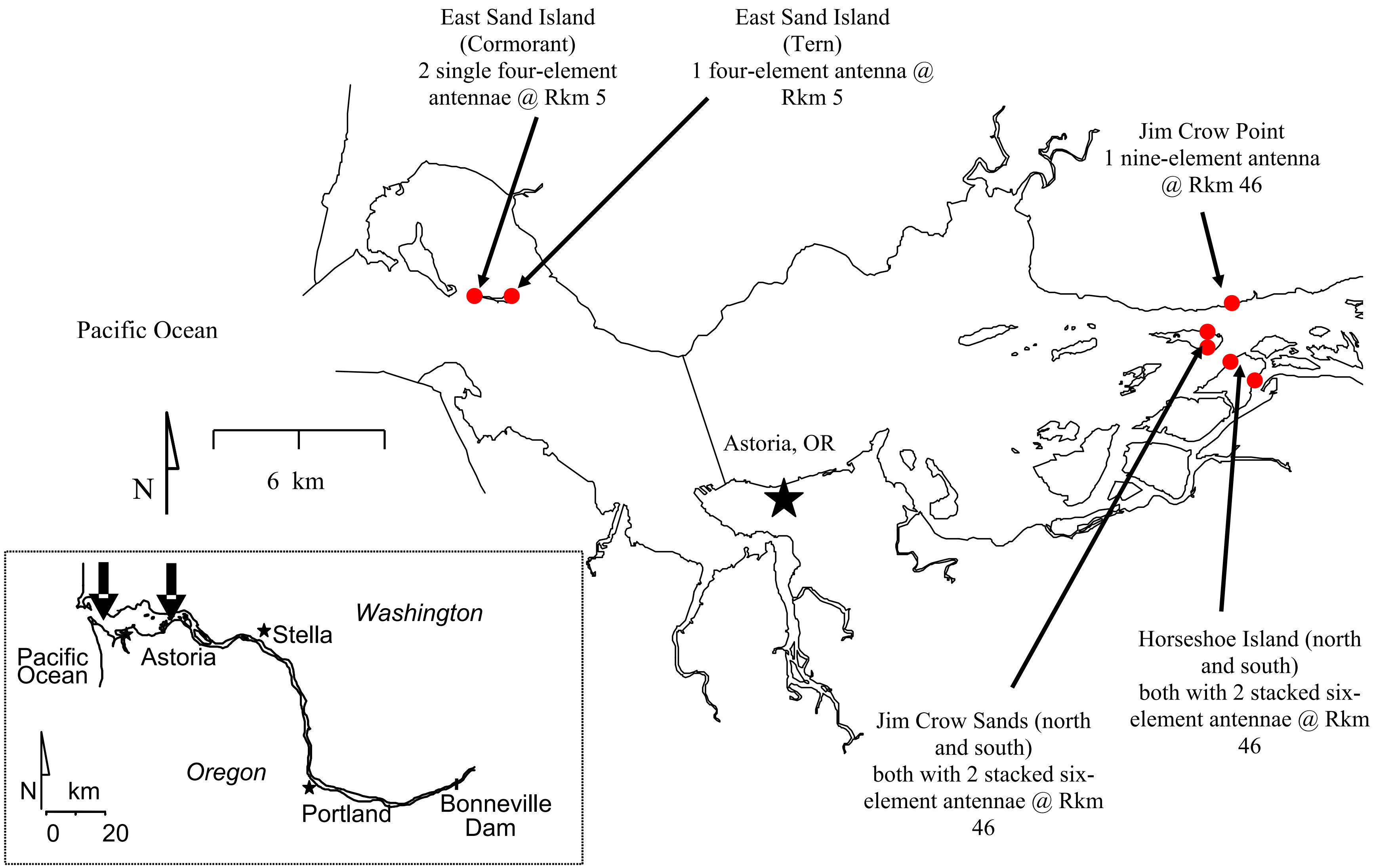


Table 5. Location and river kilometer (RKM) of radio receiver arrays and boat and plane tracking, per year. Changes in receiver location between years reflect improvements in coverage area or removal of receivers that did not adequately cover specific areas in the estuary (e.g., 2003).

Radio Receiver Sites	Stella	Jim Crow	Miller Sands Island [a]	Rice Island[b]	Mid-Estuary [b]	Astoria Bridge[c]	Boat tracks	Plane transects	East Sand Island
RKM	89	46	38	35	~26-30	22	~46-2	~229-0	8
Year	2004	2004	---	---	---	---	2004	---	2004
	2003	2003	2003	2003	2003	2003	2003	---	2003
	2002	---	2002	2002	---	2002	2002	2002	2002
	2001	---	---	---	---	---	2001	2001	---
	2000	---	---	2000	---	---	2000	2000	2000 [e]
	1998	---	---	1998	---	---	1998	1998 [d]	1998
	1997	---	---	---	---	---	1997	1997 [d]	---
	1996	---	---	---	---	---	---	1996	---

[a] Receivers not positioned at this location because of conflict with avian study.

[b] Receivers not positioned at these locations because of lack of estuarine coverage.

[c] Receivers not positioned at this location because presence of brackish water diminished reception.

[d] Plane transects focused on the region below RKM 72.

[e] Equipment problems precluded use of these data.

Table 6. Location and river kilometer (RKM) of acoustic receiver arrays, per year. In general, changes in receiver location between years reflect an increase in receivers and an improvement in river and estuarine coverage.

Acoustic Receiver Sites	Stella	Jim Crow	Seal Island	Rice Island	Miller Sands Island	Mid-Estuary	Astoria Bridge	East Sand Island	Ocean
RKM	89	46	40	36	38	~20-15	22	8	0 to -8
Year	---	2004	2004	2004	---	---	2004	---	2004
	2003	2003	2003	2003	---	2003	2003	2003 [a]	2003
	---	2002	---	2002	---	---	2002	2002	2002
	---	2001	---	---	---	---	---	2001	2001
	2000	2000	---	---	---	---	---	---	2000

[a] Only operational for the first two releases.

Detailed information on the behavior of individual migrants in the estuary was collected with boats fitted with tracking equipment and a Global Positioning System (GPS). Two boats (approximately 6 m), each equipped with one 4-element Yagi antenna and a Lotek receiver (W32 Firmware) were used to continuously monitor the behavior of individual smolts as they migrated through the estuary. Tracking was conducted over a 24h period for several days when tagged fish from a specific release were known to be in the estuary (~ 2 – 6 days post release). A boat would traverse the estuary, monitoring all of our radio tag frequencies and would track a specific frequency when a signal was detected. Once tracking began the boat was kept as close to the fish as possible by lowering the gain (i.e., decreasing the signal detection sensitivity) on the Lotek receivers. At approximately 10 minute intervals the location of the fish was recorded with the GPS unit (Garmin GPSMAP 2010) utilizing the Wide Area Augmentation System (WAAS) with an error of less than 10 m. A fish was tracked until the signal was lost and could not be re-acquired after an approximately 1 h period of time.

Acoustic telemetry in 2004:

The VR2 receivers used to monitor acoustic-tagged Chinook were manufactured by Vemco Limited. The unit can store up to 300,000 detections in flash memory and the data will be retained in the event of battery failure. The power supply is a 3.6 volt lithium cell which lasts for at least 6 months. The dimensions of the receivers are 20.5 cm (length) x 6 cm (diameter). The receivers weigh 1.2 kg in air. This submersible receiver identified and recorded coded transmitters on one of four channels.

In general, the buoy-anchoring system used to hold these receivers in place in 2004 was similar to the system we used in 2001 – 2003 (Schreck et al. 2001*b*, 2002*b*, 2003*a*). Specific differences in 2004 include the use of three buoys instead of two (2001) or four (2003), and attachment of the VR2 directly to the line. The VR2 was secured to the main line at the end opposite of the hydrophone with a stainless steel ring and near the hydrophone end with cable ties (Figure 6). All buoy-receiver systems (buoy-anchoring system combined with a VR2 acoustic receiver) had three standard floats; the ocean systems did not have a spacer rope between the last two buoys to lessen the chance of entanglement on passing boat traffic.

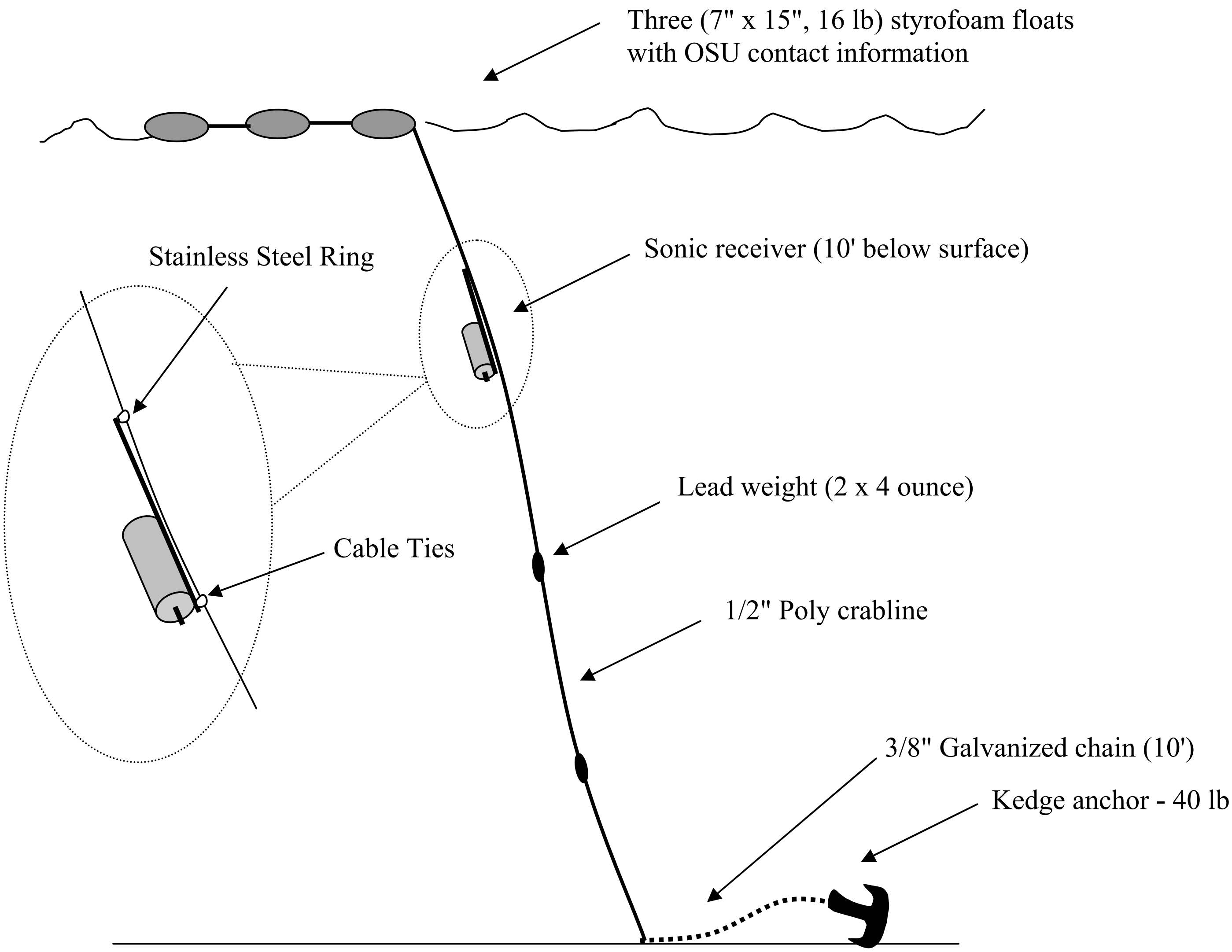


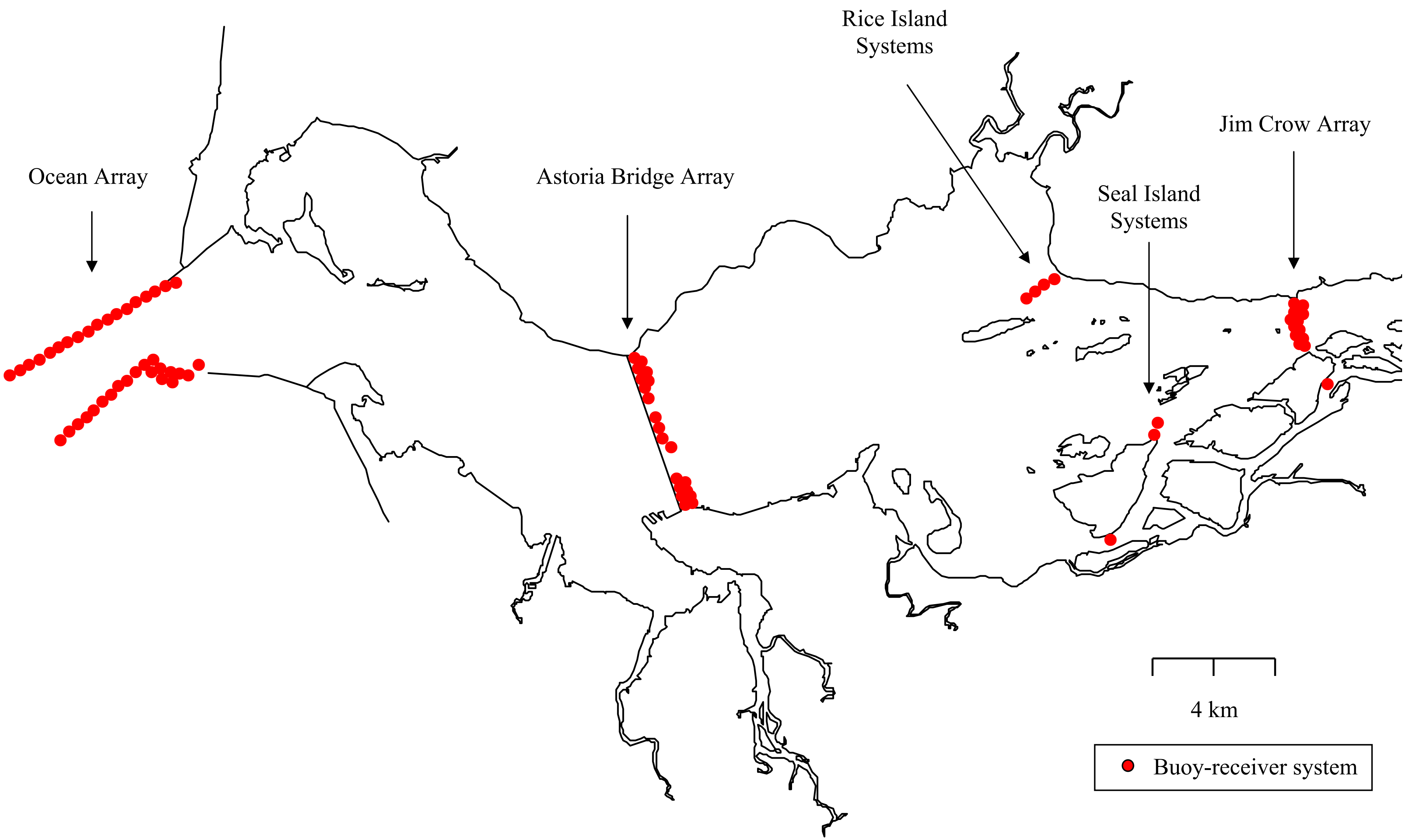
Figure 6. The buoy-anchoring system used in 2004 to deploy the VR2 receivers.

The presence/absence of acoustic-tagged spring/summer Chinook was recorded by a number of receiver arrays (a series of receivers set across a channel). The majority of receivers formed three main arrays (Jim Crow, Astoria Bridge, and the Ocean). Additional receivers were also deployed at sites throughout the upper estuary to provide information on channel usage (Figure 7). Receiver array locations for previous years are detailed in Table 6. In our validation studies, we found that receivers deployed in a zigzag pattern better detected fish than those deployed in a straight line. Receivers were thus deployed using the zigzag pattern.

The number of actively functioning buoy-receiver systems in the Ocean Array during each release in 2004 is given in Appendix 1, Table 1. All buoy-receiver systems in the estuary were functioning in each release. The corresponding numbering scheme for each array is shown in Appendix 1, Figures 1 and 2. The actual numbers of fish detected on a given array and used in any of the calculations for the acoustic portion of the study are given in Appendix 1, Table 2.

Despite the heavy loss or movement of buoys in the Ocean Array during the first (nine buoys systems) and last (seven buoy systems) release periods, detection frequency on the Ocean Array was similar to that the middle cluster of releases (two buoy systems) (see page 63, Table 11; also see Appendix 1: Table 1, Figure 2). Although most receiver losses occurred on the southern portion of the Ocean Array during all releases (Appendix 1: Table 1, Figure 2), a small, but similar percentage of acoustic tags (7-8%; averaging between clustered releases; Table 11) were consistently detected on this southern array during early, middle, and late release clusters, suggesting that there were no obvious differences. Most fish (88%) were detected on the northern portion of the Ocean Array, which experienced loss of comparatively few buoy systems (Table 11; Appendix 1: Table 1, Figure 2). To ensure against data loss in the event that a receiver failed or disappeared, we downloaded the receivers before, during, and three to four days after each release.

Figure 7. The location of the three arrays and individual buoy-receiver systems used during the 2004 field season.



Data Reduction Techniques for 2000-2004

Radio

For quality assurance purposes, the detection history was examined, and dubious radio signals were flagged using the following criteria:

1) Low detection power (≤ 50),
2) Relatively low number of detections for a given time,
3) Single line detections,
4) Detection dates greater than the battery life of the radio tag, and
5) Significant lapses in time between consecutive lines.

Once the data were flagged, the overall passage history was manually examined, and any spurious, illogical detections removed. False detections typically failed more than one of the above criteria. A total of 3,368 separate detection lines, representing 5.3% of the total detections, were removed from the entire 2004 data set.

Acoustic

For quality assurance of tag detections at receiver arrays, the number of individual detections was examined. Any code that was detected only once on an entire array was deleted from the analysis. It is possible that a single detection of a code was a result of an error from noise or from the collisions of acoustic pulses from different tags. In 2004, a total of 236 detections were deleted from the data set using this method of quality assurance, although this only represented 0.001% of the total detections. One tag code had multiple detections on the ocean array that were also deleted from the data set; the code recorded was from a tag that had not been released at that time.

CORIE Modeling

In order to better understand the role of hydrodynamics in determining fish migration patterns within the Columbia River estuary and plume, we have integrated tracking data from radio-tagged fish with that of the COlumbia RIver Estuary (CORIE) model (http://www.ccalmr.ogi.edu/CORIE). This model was developed at the Oregon Graduate Institute (OGI) School of Science & Engineering of the Oregon Heath & Science University by an interdisciplinary team of scientists under the direction of Dr. António M. Baptista. The CORIE modeling system integrates a real-time sensor network, data management system, and advanced numerical models to characterize and predict the complex circulation and mixing processes in the lower river, estuary, and near-ocean environment. Real-time hydrologic data collected from the Columbia River Estuary are integrated with remotely sensed hydrologic and oceanographic data, including tides, real-time Doppler radar, and regional weather data. Advanced numerical models are then used to produce the following simulations: short term forecasts, actual past conditions (hindcasts), characteristic climatic conditions, and scenario conditions (Baptista et al. 2005).

Analysis of CORIE model hindcast data is being used to find links between the physical processes and smolt behavior in the estuarine and nearshore environment. In particular, we examined the relationship between CORIE water particles and passive smolt behavior. CORIE model hindcast simulations were used to generate accurate geo-referenced, velocity, temperature, and salinity data that correspond to all 2002 - 2004 fish tracks. Furthermore, 25 virtual drogues (passive particle tracers representing individual water molecules) were released at the precise time and location of all 2002-2004 fish tracks. The model will "track" the movement and velocity of the water particle in three dimensions using actual location and water velocity data that are built into the model. Depending on the release location in the estuary, the precision of the geospatial data can be down to 1 m in size. Analysis of data from the CORIE model with respect to salmon migration behaviors utilized G3 (CORIE 3-D visualization software), IDL (Interactive Developers Language), and Perl (Practical Extraction and Report Language) to extract, analyze and visualize large-scale spatial and temporal patterns of CORIE velocity, CORIE salinity, and CORIE temperature in the Columbia River estuary from model hindcast simulation data. Current methods for extracting data and analyzing data from the CORIE model are still under development (Baptista et al. 2005). Thus current findings that follow should be judged as preliminary.

Survival Estimates

The acoustic arrays and fixed radio sites provided multiple detection sites below BON, therefore, the "complete capture history" protocol (Burnham et al. 1987) was used. The single release-recapture model, which is based on the models of Cormack (1964), Jolly (1965), and Seber (1965) was used to generate survival and detection probabilities. The SURPH ("Survival Under Proportional Hazards", Smith et al. 1994) program, Version 2.2a was used to estimate detection probabilities and their associated standard errors. All results can be found in the Appendix 1: Tables 3-4 (acoustic) and Table 6 (radio).

Single release-recapture Cormack-Jolly-Seber (CJS) survival estimates are subject to seven assumptions (Peven et al. 2005). The design of our study does not lend itself to analysis of these assumptions because there was no physical recapture of our tagged fish. However, for heuristic reasons, we did go through the exercise of formally testing assumptions five and six, known as Burnham tests 2 and 3 (Burnham et al. 1987; Peven et al. 2005) via Chi square (with Yate's correction) Goodness of Fit test. If there were less than 100 observations, then we also used Fisher's Exact Tests to corroborate the Chi square tests (Appendix 1, Tables 5 and 7). Test 2 is known as the 'survival' tests because it tests the assumption that all fish alive at an upstream receiver location have an equal probability of surviving to the next receiver array downstream. Test 3 is known as the 'recapture' test because is tests the assumption that all tagged fish alive at a receiver location have an equal probability of being detected. Out of 49 comparisons with Test 2, only six were significant, and out of 37 comparisons with Test 3, only two were significant — one for each tag type on the same fish (ROR steelhead), during the same release period. We note that the exclusion of these releases would not change our results or the conclusions based on these results. The releases in question follow the survival estimate trends of the remaining releases for that given fish species, year, and passage type. These tests were originally designed to assess handling effects and route of passage on fish marked with passive tags, when marked fish were subsequently recaptured and handled at each successive downstream site (Burnham et al. 1987; Peven et al. 2005). Hence there was a need to ascertain whether upstream recaptures and routes of passage (e.g., spill, turbine, bypass) were independent of recapture efficiency and survival downstream. Quoting from Peven et al. (2005):

> "…assumption (A6) (recapture test) could be violated if downstream detections were influenced by upstream passage routes taken by the smolts. Violation of this assumption is minimized by placing hydrophone or acoustic (and radio) arrays across the breadth of the river or below the mixing zones for smolts following different passages at the dam."

All of our fish were released from barges downstream of the lowermost dam on the FCRPS (Bonneville) or from Bonneville itself and were thus free to migrate in the ~233 rkm of unobstructed river and estuary to the ocean. Furthermore, our receiver arrays were setup to cover the breadth of the river and estuary (Figures 4, 5, and 7; see also our high detection efficiencies, Appendix 1, Tables 4 and 6). Quoting from Peven et al. (2005):

> "The reach survival estimates from SRM may be negatively biased for three different reasons (the third relates to PIT tagged fish). If there is post-release handling mortality, that mortality would be incorporated in the first one or two reaches below the initial release location. Consequently, survival may be most susceptible to handling bias. The more invasive the tagging process (i.e., radio-tag or acoustic-tag), the greater the chance of bias. Post release tag loss will also negatively bias survival estimates…Radio-tag and acoustic-tag studies are not subject to bias from post-detection bypass mortality because the detected fish are never physically segregated from the nondetected fish crossing a detection array."

Our results suggest that tag type did not affect survival in steelhead (radio versus acoustic; refer to spring/summer Chinook and steelhead Results and Discussion). However, tag type marginally affected survival of spring/summer Chinook during 2004. Survival data for spring/summer Chinook is strongly relative to release date, and fish from each tag type were not released on the same day. Therefore, the cause of the variation in survival estimates could also potentially lead to an erroneous conclusion that there were differences in fish performance due to tag type. The data is the first set available for these fish in the saltwater environment. Also, there is no other data (i.e., control) over the same stretch of river and estuary with which to compare our survival results. Finally, we note that travel times between our telemetry fish and PIT tagged fish were comparable and that the trends in mortality (as indicated by detections on the piscivorous avian colonies in the estuary) were similar to those for PIT tags (refer to Results and Discussion section for each fish species/strain for more detail). This leads us to believe that radio tags had little or no deleterious effect on spring/summer Chinook, fall Chinook, or steelhead; similarly, acoustic tags had little or no deleterious effects on steelhead.

Detection histories for each fish were translated into a binary capture history matrix to reflect detection status, where "detected" = "1" and "not detected" = "0". This matrix included the specific capture history of all fish released. An example of a capture history is: 1101, in which the fish was released (**1**101), detected at the first array (1**1**01), not detected at the second array (11**0**1), and then detected again at the final array (110**1**).

The arrays used in each year's (2000-2004) estimates vary. For radio data, years 2002-2004 were used for SURPH estimates; for acoustic data, years 2001-2004 were used (Tables 3 and 4). We chose to use data from these years for SURPH estimates because the use of extensive receiver arrays and large numbers of fish per release increase the detection probability of fish per release.

For the radio data, the Stella, Washington array (rkm 89) was in place for all modeled years, whereas the Jim Crow Array was in place only during 2003 and 2004, and the final array consisted of fish detected downstream of the Jim Crow Array. Specifically, this final array consisted of fish detected while conducting boat tracks, combined with fish detected on East Sand Island. During 2002 – 2003, the middle estuary was extensively used, with receiver arrays located at Rice and Miller Sands Islands, as well as the Astoria-Megler Bridge (Table 5).

The acoustic arrays also changed with the numbers of receivers in place and the locations of arrays. For the most part, the Jim Crow Array, Astoria-Megler Bridge Array, and the Ocean Array remained similar in the number and location of individual buoy-receiver systems in 2002 – 2004 (Table 6). In 2001, there was an additional array for two of the releases at East Sand Island.

The Ocean Array was the final detection point in the system. In this last sampling interval, it was not possible to differentiate between "death" and escapement for the fates of undetected fish.

Therefore, the parameter "λ", describes this joint probability of surviving the time interval and being detected in the last sampling interval.

The key assumptions associated with the single release-recapture model, as discussed in Burnham et al. (1987) and Skalski et al. (2001) are as follows:

1) Individuals marked for the study are a representative sample from the population of interest.
2) Survival and capture probabilities are not affected by tagging or sampling, that is, tagged animals have the same survival probabilities as untagged animals.
3) All sampling events are "instantaneous", that is, sampling occurs over a negligible distance relative to the length of the intervals between sampling events.
4) The fate of each tagged individual is independent of the fate of all others.
5) All tagged individuals alive at a sampling location have the same probability of downstream survival.
6) All tagged individuals alive at a sampling location have the same probability of being detected.
7) All tags are correctly identified and the status of smolt (i.e., alive or dead) is correctly assessed.

To calculate a yearly average survival probability ($\hat{\bar{S}}_{array}$) to a specific array for each type of fish (BRG or ROR) or for each telemetry method (radio or acoustic), we used the arithmetic mean (simple average, Burnham et al. 1987):

$$\hat{\bar{S}}_{array} = \frac{\sum_{i=1}^{n} \hat{S}_i}{n}$$

where i = individual releases and n = the number of releases.

The empirical variance associated with this simple average was calculated as follows:

$$Var(\hat{\bar{S}}_{array}) = \frac{\sum_{i=1}^{n} (\hat{S}_i - \hat{\bar{S}}_{array})^2}{n(n - 1)}$$

Using this variance, which is related to the standard error (*se*) by

$$Var(\hat{\theta}) = [se(\hat{\theta})]^2$$

we calculated a 95 % confidence interval:

$$\hat{\bar{S}}_{array} \pm t_{\alpha/2,n\text{-}1}\, se(\hat{\bar{S}}_{array})$$

where t is obtained from a Student's t distribution for a two-tailed test and n = the number of releases (groups of fish) in a given year.

The theoretical variance of $\hat{S}_{array}$ is a function of the estimate of $\hat{S}_{array}$. Therefore, it is often recommended to weight the average and empirical variance to eliminate the correlation between them (Burnham et al. 1987). To weight the variance, we used

$$W_i = \frac{1}{\left(\frac{\hat{Var}(\hat{S}_i)}{\hat{S}_i^2}\right)}$$

And the formula for the weighted average becomes

$$\hat{\bar{S}}_{array} = \frac{\sum_{i=1}^{n} W_i \hat{S}_i}{\sum_{i=1}^{n} W_i}$$

In this report, we refer to simple averages (all estimates receive the same weight of 1/n). When the survival and detection probabilities are near 1 (or 100%) for an individual release, the result is an

exceedingly high weight (W_i) relative to the other releases. Consequently, the overall estimate of $\hat{\bar{S}}_{array}$ will also be near 1, since releases near 1 contribute un-proportionately to the overall estimate. We feel the weighted average does not represent the central tendency of the estimate in our study; although the weights are not used in a weighted average, they are shown in Appendix 1, Tables 3 – 5. Both simple and weighted averages (unequal weights) are presented in Appendix 1, Tables 8 (acoustic) and 9 (radio).

Statistical Analyses

In-river Migration Rate Analyses

We conducted regression analyses to determine the extent to which migration rate was influenced by river flows from BON. The average migration rate for each individual release was calculated for each species and treatment type, and then regressed against river flow. For spring/summer Chinook the average migration rate for each release was calculated during 1996-1998 (BRG and ROR) and 2004 (BRG only). Migration rates were calculated in a similar fashion for fall Chinook and steelhead during 2000-2003.

For spring/summer Chinook in 2004, all radio and acoustic telemetry data were analyzed separately, with the exception that migration rates and survival estimates for the two technologies were tested at Jim Crow (rkm 46). At this point, both receiver arrays overlapped, enabling us to test the null hypothesis that the tag size and mass would not affect the migration rate or survival in spring/summer Chinook. Migration rate between acoustic- and radio-tagged spring Chinook was analyzed via the mixed model procedure (PROC MIXED procedure of SAS, version 9.1), where 'tag type' and 'release period' were held as fixed class variables that were incorporated into the model statement. A saturated model was employed, and included 'release period', 'tag type', and the interaction between the two ('release period*tag type').

Survival Analyses

Survival analyses were conducted for spring/summer Chinook data collected in 2004, and on fall Chinook and steelhead data collected during 2002-2003. Using raw data (number of fish detected and number released), data were analyzed via the maximum likelihood ratio for logistic regression. Quasilikelihood ratio was used if the data were overdispersed (deviance/DF > 1.0). Logistic regressions were conducted via the PROC GENMOD procedure of SAS (version 9.1).

Saturated models were employed first, and included general information such as 'release period' (early, middle, and late), 'release day', 'river flow' (average Bonneville discharge during the 24 hours after release). Additional information, including 'origin' (hatchery or wild), 'collector dam' (Lower Granite or McNary) for barged fish, 'passage type' (BRG or ROR), and 'tag type' (radio or acoustic) were also used, and were specific to the fish species and the questions addressed for a particular year. Insignificant explanatory variables were removed singularly in a stepwise fashion to leave a parsimonious model with the lowest dispersion value possible.

For cases in which known hatchery and wild steelhead were tagged (2002-2003) or in which barged hatchery fish were tagged from both Lower Granite (LGR) and McNary (MCN) Dams (2002), the above procedures were followed to test the hypotheses that no difference in survival would occur for either barged hatchery or wild fish or barged hatchery fish obtained from LGR or MCN. If the statistical analyses enabled us to accept these null hypotheses, the data were pooled and analyses on BRG and ROR comparisons commenced.

Avian Predation Analyses

To assess the relative amount of avian predation on juvenile salmon, we tallied the total number of individual tag detections on Rice Island (1996-1998, 2001) and on East Sand Island (1996-

1998, 2001-2004) for the respective species and treatment type (BRG, ROR). During 1996, tags were identified via receivers on aircraft flying transects and were used to detect tags on the piscivorous waterbird colonies on Rice (1996-1998, and 2001) and East Sand (2001-2004) Islands. During 1997-1998 and 2000-2001, both boat tracking and plane transects were used to detect tags on these islands; during 2002-2004, boat tracks and two fixed radio receiver stations (one located on the east portion of the island, the other on the western portion) were used to detect tags on the islands. The proportion of fish detected on the island divided by the total released below BON enabled us to produce an index of mortality due to avian predators.

Tags detected on the islands over an extended period of time (typically > 12 hours) or pinpointed by plane or boat and found to not be moving through several tidal cycles were deduced to be juvenile salmonid mortalities resulting from avian predation.

The proportion of mortalities (number of fish detected on the bird island/total number released below BON) resulting from avian predation were analyzed via the maximum likelihood ratio for logistic regression. Statistical analyses were conducted as described in the previous section.

For cases in which known hatchery and wild steelhead were tagged (2002-2003) or in which barged hatchery fish were tagged from both LGR and MCN (2002), the above procedures were followed to test the hypotheses that no difference in survival would occur for either barged hatchery or wild fish or barged hatchery fish obtained from LGR or MCN. If the statistical analyses enabled us to accept these null hypotheses, the data were pooled and analyses on BRG and ROR comparisons commenced.

RESULTS AND DISCUSSION

SPRING/SUMMER CHINOOK

Migratory Rates and Patterns

In-river migratory rate

Radio-tagged, BRG spring/summer Chinook that were detected at the transition site (Stella, rkm 89) migrated 130 – 136 km downstream in 30 – 151 h (1 – 6 days). The median and mean migration rate from the release location to this site for all fish and releases combined was 3.5 and 3.4 kilometers per hour (km/h), respectively. Among individual fish, the rate to Stella ranged from 0.9 – 4.5 km/h. The median and range of migratory rates for each release is given in Table 7.

In 2004, a new fixed radio site was placed in a small shallow channel (south side of Crims Island) that was outside the range of the other two radio antennas being used at this transition site (Figure 4). This site was used to determine if the transition site was missing fish due to the lack of coverage of this alternate channel for previous years. However, no fish were detected in this channel.

Radio-tagged, BRG spring/summer Chinook released below BON migrated 173 – 179 kilometers downstream in the Columbia River to the estuary (Jim Crow, rkm 46) in 29 – 165 h (1 – 7 days), compared with 44 – 735 h (2 – 31 days) for acoustic-tagged fish. The median and mean migration rate from the release location to this site for all radio-tagged fish was 3.3km/h; for acoustic-tagged fish, these rates were 2.9 and 2.8 km/h, respectively. Migration rates ranged among all radio-tagged fish from 1.1 – 6.0 km/h; for acoustic-tagged fish, the range in rates was 0.2 – 4.0 km/h (Table 7, Figure 8). The large variations in migration times from the current barge release site to the estuary indicate that spring/summer Chinook do not reach the estuary as one distinct group of fish.

Because acoustic tags have a much longer life than radio tags (Table 1) and significant differences in the maximum travel time between radio and acoustic tags were apparent (Figure 8), we removed three acoustic-tagged fish (two from the first release, and one from the second releases of the first release period) that had travel times exceeding the guaranteed radio tag battery life. This enabled a more even comparison of travel times between the two tag types.

There was a slight but significant increase in migration rates of both acoustic- and radio-tagged Chinook, from early to late release periods (Figure 8), which is due in part to increases in river discharge (Figures 8 -10). As the season progressed, median migration rates and average FL of these fish decreased (Table 7). This suggests that migration rate of spring/summer Chinook may be more dependent upon river flow than fish size (FL) over the range of sizes that we tagged. It is equally plausible that fish tagged during the latter part of the season were more smolted (and ready to outmigrate), and that these smoltification levels were independent of fork length over the range of sizes that we tagged.

The variation between fish of a given tag type was greater than the increase in migration rates over all release periods. Radio-tagged fish migrated at a slight but significantly greater rate over all release periods. These fish also had a wider distribution of migration rates than their acoustic-tagged counterparts. All of the explanatory variables in the saturated model were significant, so none were removed. This saturated model included 'release period', 'tag type', and the interaction between the two ('release period*tag type') (Appendix 2.A.1.). Because of the lack of overlap in our acoustic receiver location at the Jim Crow site (rkm 46) with the location of sampling via the PIT tag trawl (Dick Ledgerwood, NOAA Fisheries, pers. comm.), we do not believe that migration rates of our acoustic-tagged fish can be compared equivocally with rates of PIT-tagged fish sampled further upstream. Also, the Jim Crow site is influenced by tides to a greater extent than our radio receiver site 43 km upstream. However, our radio receiver sites enabled us to compare migration rates to the lower river for our radio-tagged fish with those of PIT-tagged fish sampled via the PIT tag trawl. The rates for the two tag types were comparable at this lower river location.

Table 7. Comparison of median migration rates of spring/summer Chinook from the release site below Bonneville Dam to the transition site (i.e., Stella, rkm 89) and Jim Crow (rkm 46) in 2004. Also shown are ranges in migration rates and the number of fish (N) detected for which migration rates were calculated. Average fork lengths (FL; mm) are for fish exhibiting median, minimum, and maximum migration rates.

Release to Transition Site Release Date	**Tag type**	**Median**	**FL for Median**	**Range**	**FL for Min**	**FL for Max**	**N**
May 5	Radio	3.4	153	2.4-4.0	163	157	88
May 6	Radio	3.3	167	2.1-3.9	148	153	88
May 19	Radio	3.0	148	0.9-4.0	148	149	88
May 20	Radio	3.4	145	2.3-4.2	139	148	85
May 30	Radio	3.6	150	1.5-4.5	143	155	93
May 31	Radio	3.9	149	2.3-4.4	145	149	90
Release to Jim Crow							
May 3	Acoustic	2.7	170	0.6-3.3	141	169	66
May 4	Acoustic	2.9	162	0.2-4.0	145	145	109
May 5	Radio	3.2	159	1.3-4.0	151	161	92
May 6	Radio	3.2	156	1.5-6.0	144	148	88
May 16	Acoustic	2.7	146	2.0-3.1	147	151	97
May 18	Acoustic	2.7	147	1.1-3.3	141	153	84
May 19	Radio	3.0	146	1.1-3.7	148	145	79
May 20	Radio	3.3	146	2.3-3.7	139	149	70
May 28	Acoustic	3.1	147	2.4-3.9	145	153	80
May 29	Acoustic	3.1	145	2.1-3.9	151	150	82
May 30	Radio	3.5	148	1.8-4.5	141	155	86
May 31	Radio	3.5	148	2.6-4.3	145	148	83

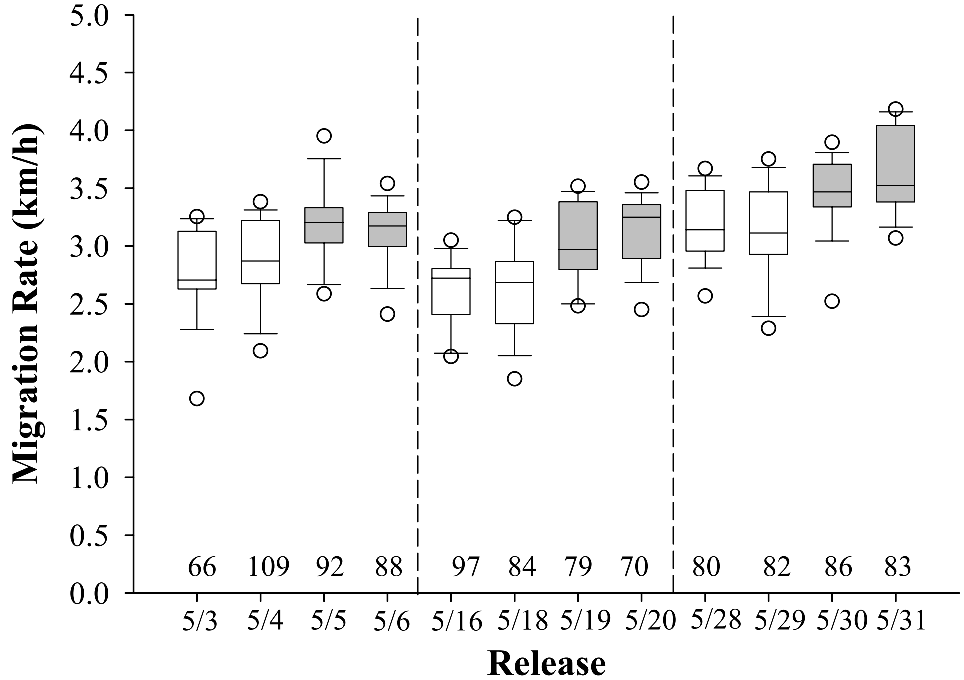


Figure 8. Migration rates of spring/summer Chinook to the Jim Crow site (rkm 46), comparing fish tagged with acoustic- (white boxes) and radio-tags (gray boxes). Boxes represent 25th -75th percentile ranges, horizontal lines within the boxes are the median rates, and vertical lines above and below the boxes are the 10th -90th percentile ranges, and the dots depict the 5th -95th percentile ranges. Sample sizes are shown above the release dates.

ROR spring/summer Chinook migrated to rkm 89 (Stella, WA) more rapidly than their barged counterparts during 1996-1998 (Figure 10). Most of the variation in migration rate in ROR fish could be explained by flow, in contrast to barged fish. It is unclear why ROR fish migration rates were more influenced by flow than barged fish. The difference in migration rates between the two treatment types did not translate into differences in estimated survival (Jepsen et al., *in preparation*). Radio-tagged spring/summer Chinook traveled at the same rate as PIT-tagged spring/summer Chinook, indicating that there were minimal to no tag effects on swim performance (Ledgerwood et al. 1998).

Earlier work indicated that most spring/summer Chinook moved rapidly away from the current barge release sites downstream of BON, moving > 0.8 rkm within 15 minutes of release (Schreck et al. 1993). This rapid exodus took these fish past areas known to be high in northern pikeminnow (*Ptychocheilus oregonensis*) abundance (Schreck et al. 1993).

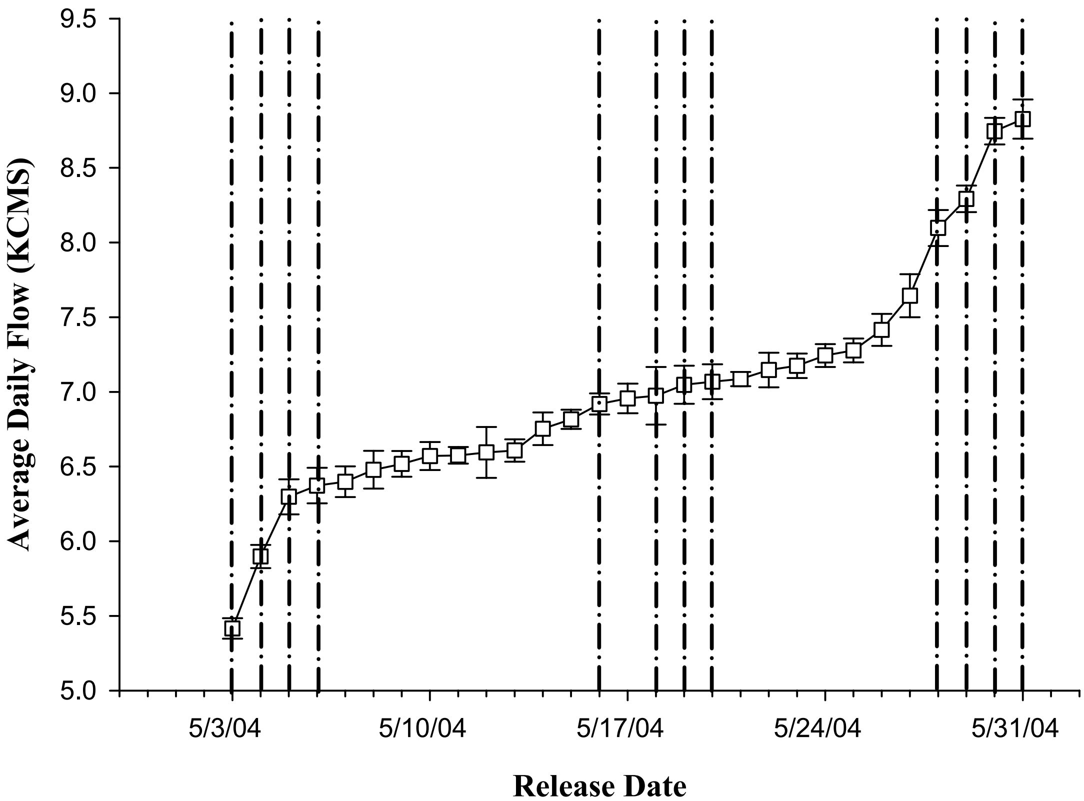


Figure 9. Average daily flow (error bars ±SEM) from Bonneville Dam during the course of the 2004 acoustic- and radio-tagged spring/summer Chinook releases (http://www.nwd-wc.usace.army.mil/perl/dataquery.pl). Vertical dashed lines are the release dates.

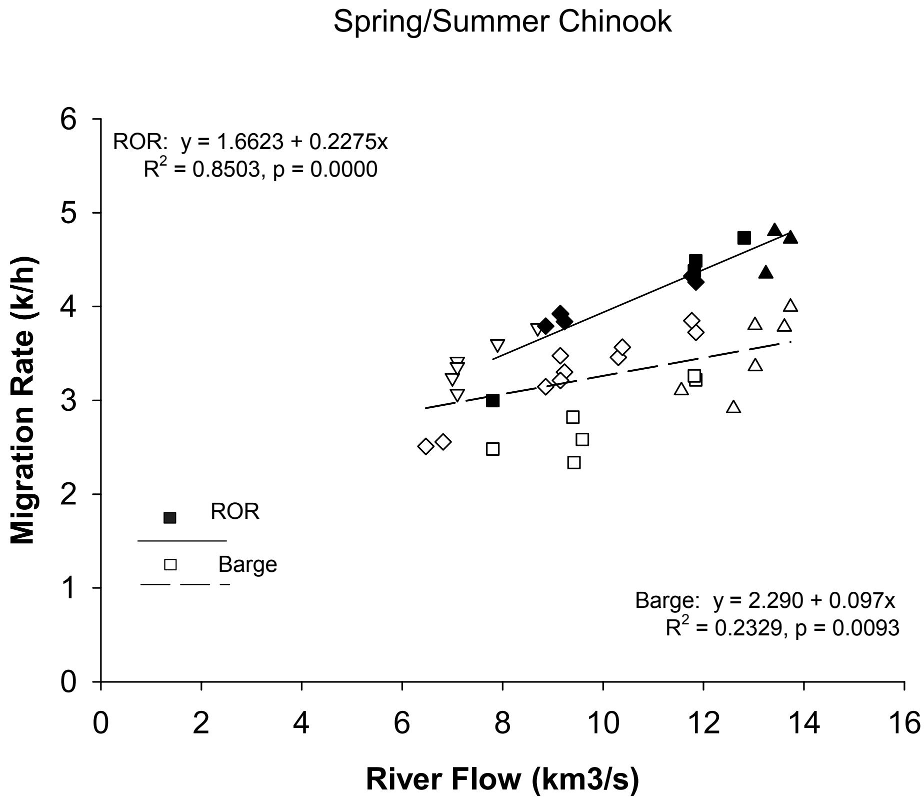


Figure 10. Average river flow from Bonneville Dam (24 hours post-release) regressed against the average migration rate for individual releases (group of fish) of spring/summer Chinook during 1996-1998 (BRG and ROR) and 2004 (BRG only), from the release site below Bonneville Dam to the fixed radio receiver site near Stella, WA (rkm 89). For barged fish, open squares designate 1996, triangles, 1997, diamonds, 1998, and inverted triangles, 2004. For ROR fish, closed squares designate 1996, triangles, 1997, and diamonds, 1998.

Estuarine migratory patterns and rates

Using acoustic telemetry, we collected data on a number of individual fish for the entire span of their migration in the Columbia River estuary. The median length of time to migrate through the entire estuary (~ 47 km, Jim Crow to Ocean) was 27 h (range: 13 – 111 h) (Table 8). To find explanatory variables for the variation in times, we examined estuarine migration patterns and rates.

Table 8. The length of time to for spring/summer Chinook migrate through the entire estuary (~ 47 km, last detection at Jim Crow and the initial detection on the ocean array) in 2004. A count of the number of individuals included in the median, minimum, and maximum hours to migrate for each release and pooled releases. Average fork lengths (mm) are for fish that had the median, minimum, and maximum migration rates.

Release Day	Count	Median	FL for Median	Minimum	FL for Min	Maximum	FL for Max
May 3	29	26.1	179	16.4	177	47.8	165
May 4	45	38.0	148	15.0	151	63.4	165
May 16	37	25.6	151	14.2	151	52.0	141
May 18	43	27.2	144	17.0	149	50.9	154
May 25	56	24.8	146	12.5	153	44.6	150
May 26	58	25.8	147	12.6	158	111.3	157
Pooled	268	26.7	---	12.5	---	111.3	---

Upper estuary (acoustic):

Of the acoustic-tagged fish detected at the Jim Crow Array, 99% used the main shipping channel for their outward migration, and only 1% used a smaller channel on the southern side of the river at this array (Table 9, Figure 11). Downstream of the Jim Crow Array, a number of islands form a mosaic of channels. Acoustic receivers placed in these channels enabled us to determine the proportion of fish migrating through them. Based on data from these receivers we identified four primary routes, shown in Figure 11. Below the Jim Crow site, the majority of the fish (66%, 341 of 518) remained in the main shipping channel, whereas 28% migrated north of Rice Island, and 6% utilized smaller side channel habitats. Routes at these locations were dependent upon release day (Table 10). These percentages were different for steelhead studied in 2003 (Schreck et al. 2003*a*), when the majority of fish remained in the main shipping channel (76%, 348 of 458), and only 8% (pooled releases and types) used the channel north of Rice Island and 16% used the smaller side channels (see section on "Steelhead"). It is not known if the use of the smaller channels is a "choice" that fish make or if it is more dictated by hydrologic conditions.

Table 9. Percentage of spring/summer Chinook passing one of two routes (north or south) at Jim Crow Point. Routes were not dependent upon release days (X^2 = 8.92, 5 d.f., p = 0.1122).

Release day	% using Northern Route	% using Southern Route
May 3	100	0
May 4	98.17	1.83
May 16	95.88	4.12
May 18	98.81	1.19
May 25	100	0
May 26	100	0
Pooled	99	1

Table 10. Percentage of spring/summer Chinook passing different routes below Jim Crow Point. Note that routes were dependent upon release days (X^2 = 27.90, 10 d.f., p = 0.0019).

Release day	% using North Rice Island Route	% using Main Shipping Channel	% using Snag and Seal Islands
May 3	28.79	69.69	1.52
May 4	27.52	64.23	8.25
May 16	19.59	70.10	10.31
May 18	19.05	73.81	7.14
May 25	30.00	67.50	2.50
May 26	46.34	50.00	3.66
Pooled	28	66	6

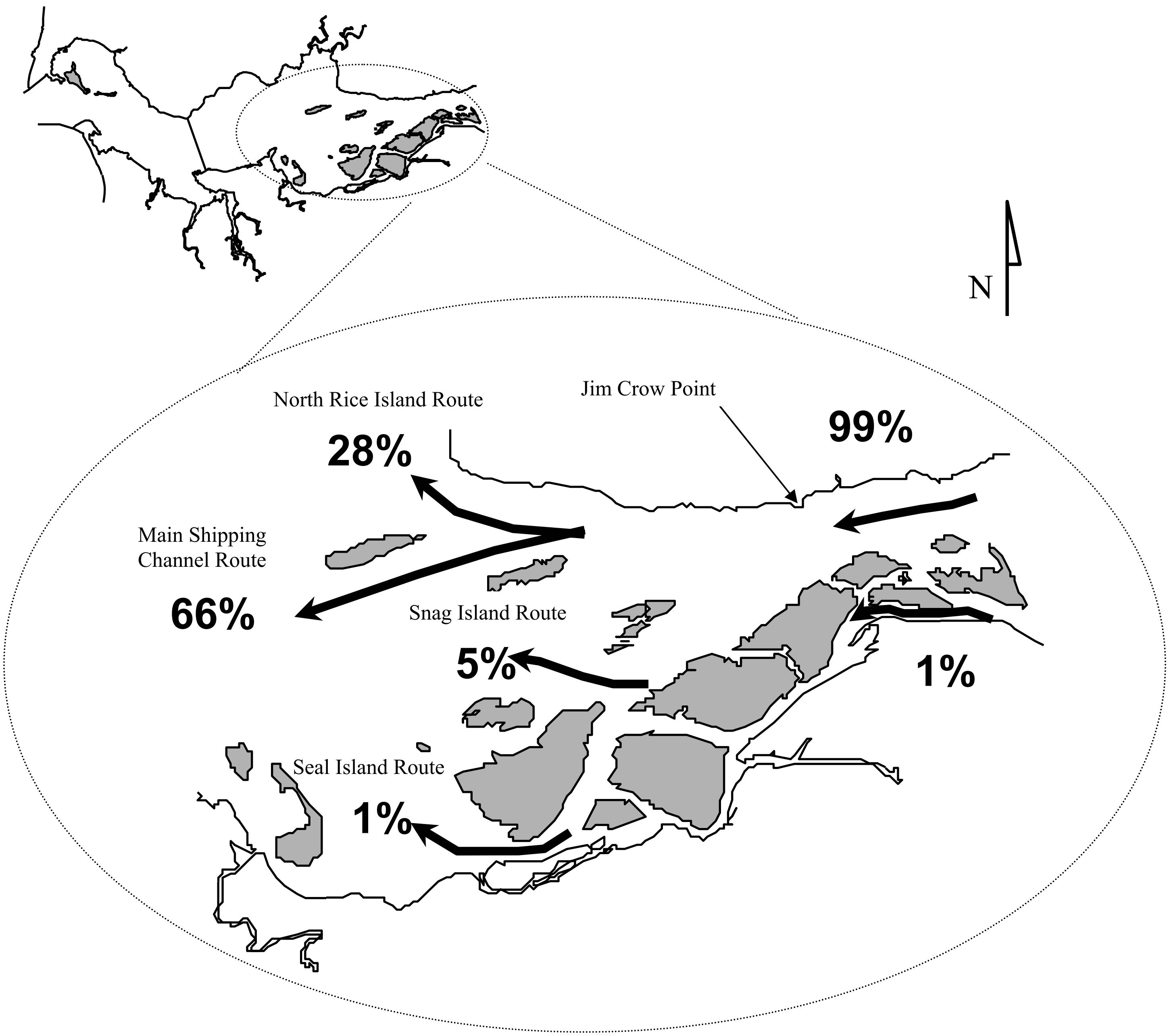


Figure 11. Overall percentage of barged juvenile spring/summer Chinook using different migration routes in the upper Columbia River Estuary, based on acoustic receivers. Routes were dependent on release dates (see Tables 10 and 11).

Mid estuary (radio):

Migration routes of radio-tagged spring/summer Chinook were determined by tracking fish with boats. The majority of fish that were tracked within the estuary were first detected in or near the main shipping channel south of Rice Island. Subsequently, fish tended to use one of three general "migration corridors" to travel the estuary. The actual fish tracks for 2004 can be seen in Figures 12 – 14. The first general migration corridor was within the contemporary shipping channel (southwest from Rice Island), whereby these migrants eventually passed near the Oregon shore and through the south channel under the Astoria Bridge. The second migration corridor was a route proceeding northwest through a relatively shallow area downstream of Rice Island and eventually entering the northern shipping channel near the Washington shore. The final migration corridor was a route proceeding in a southwesterly direction on the Oregon side of the estuary until just upstream of the Astoria-Megler Bridge, at which point fish would enter a smaller channel oriented to the northwest (this channel is near the midpoint of the Astoria-Megler Bridge). This final migration corridor or passage route was not observed for spring/summer Chinook tracked by boat in 2004, although fish were known to be using this channel from detections of fish on acoustic receivers. Although these passage routes illustrate some of the general patterns of downstream migration, fish may take more than one of these routes depending on tidal influences. For instance, a fish may traverse the sand flats in the middle of the estuary to the Washington side, encounter an incoming tide and move back across to the Oregon side of the estuary, where it may take a different route downstream on the next outgoing tide.

The patterns described here are similar to those recorded in previous years for both steelhead and fall Chinook (Schreck et al. 2000, 2001*a*, 2002*a,* 2003). We hypothesize that fish traversing the shallow flats to the Washington side are following higher water velocities in small subsidiary channels through this area. Modeled tidal flows project that the North Channel has twice as much flow volume as the primary navigation channel, on both ebb and flood tides, near the Astoria Bridge (Hamilton 1990). During ebb flows the North Channel receives flow from the navigation channel through subsidiary channels near Tongue Point. Migration routes appear to coincide with this flow pattern. Few fish were tracked past the Astoria Bridge relative to steelhead tracks in previous years, possibly due to different hydrological conditions resulting in higher salinities near the bridge or fish located deeper in the water column, both scenarios in which radio signals could be attenuated.

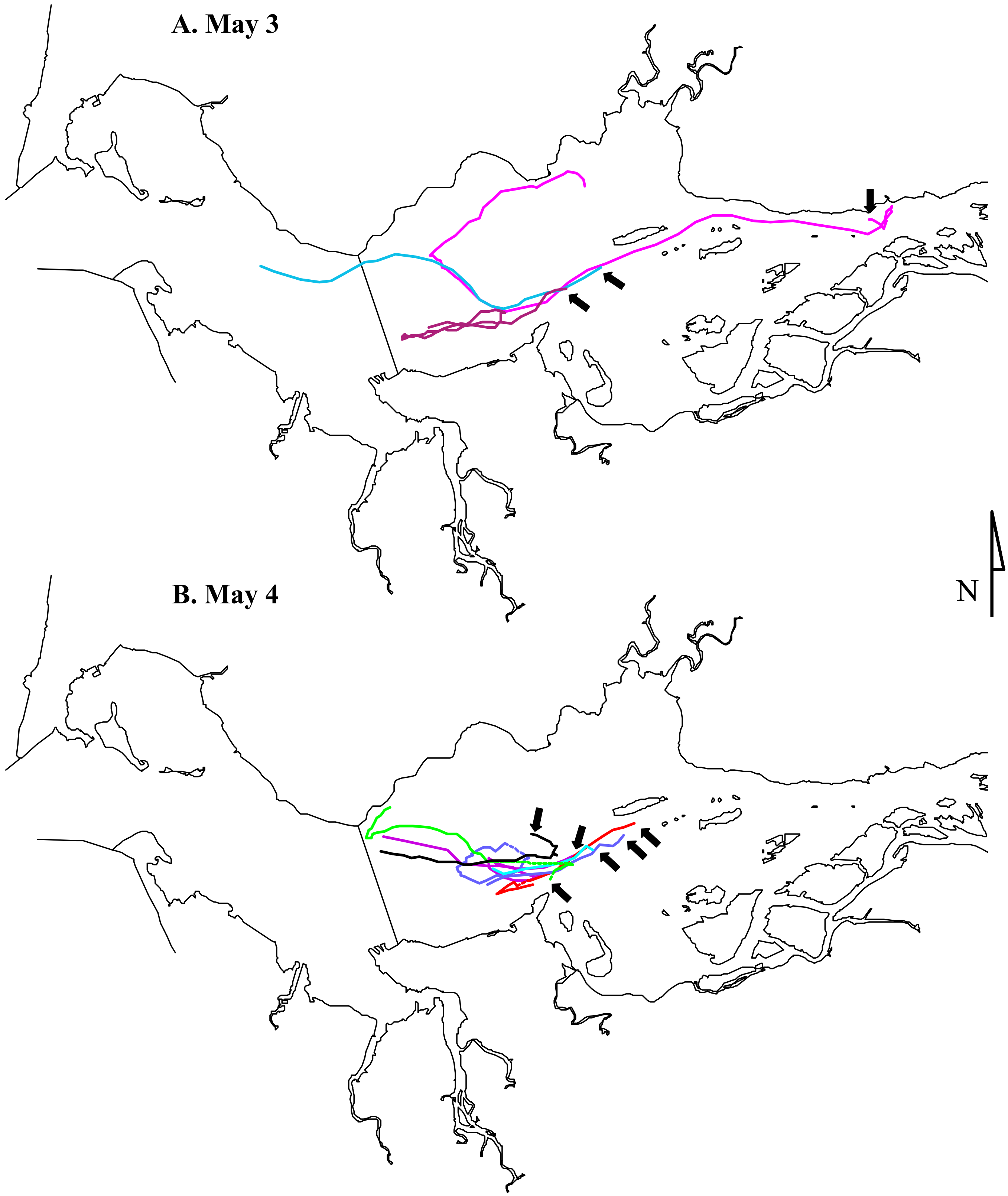


Figure 12. Migration routes of individual barged juvenile spring/summer Chinook through the Columbia River Estuary, based on tracking radio-tagged fish with boats. Release dates for fish were (A) May 3 and (B) May 4, 2004. Different colored lines represent individual fish with an arrow indicating the start of tracking for each fish. Dotted lines are shown when the time between waypoints (locations where fish were detected) was greater than one hour.

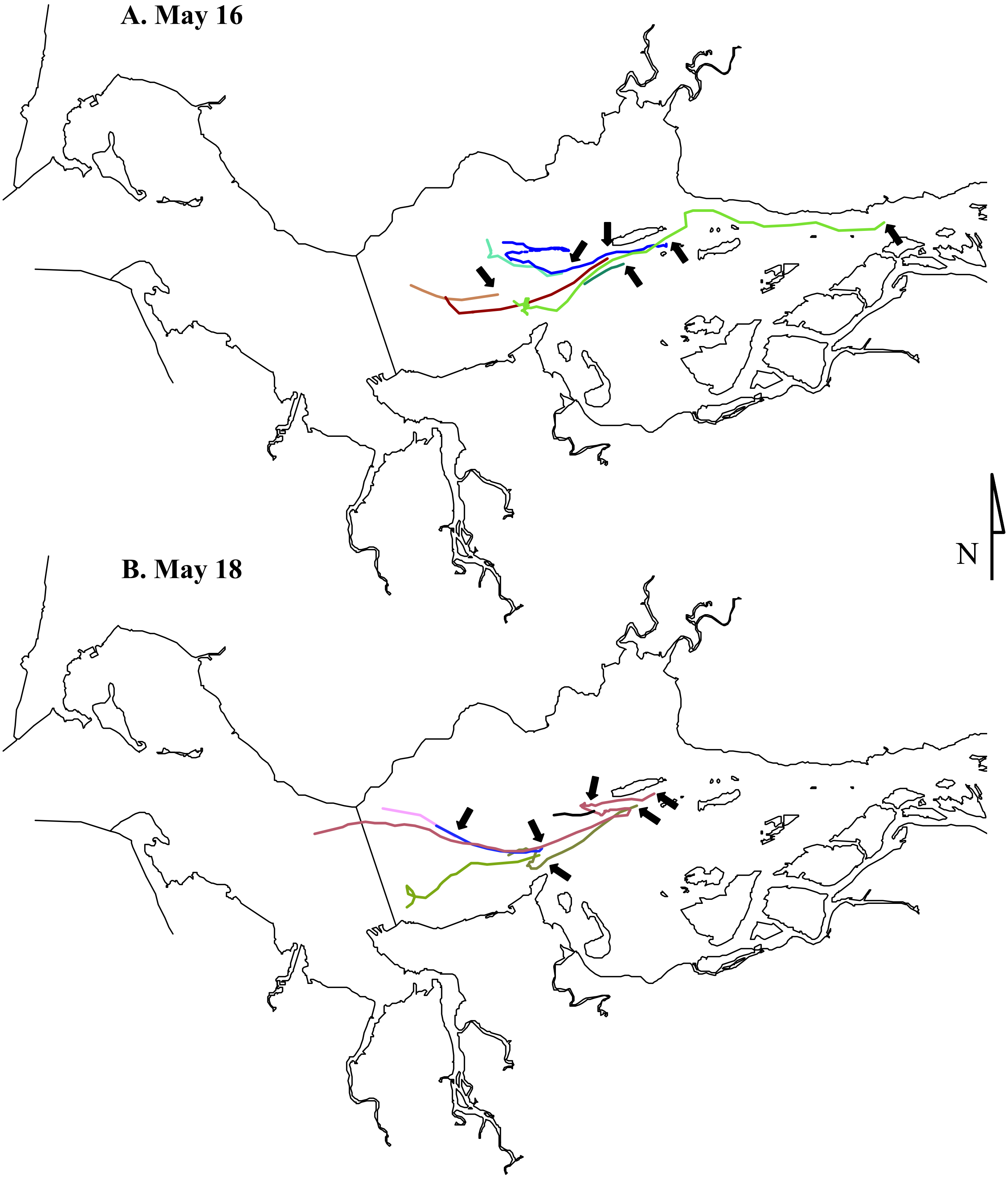


Figure 13. Migration routes of individual barged juvenile spring/summer Chinook through the Columbia River Estuary, based on tracking radio-tagged fish with boats. Release dates for fish were (A) May 16 and (B) May 18, 2004. Different colored lines represent individual fish with an arrow indicating the start of tracking for each fish. Dotted lines are shown when the time between waypoints (locations where fish were detected) was greater than one hour.

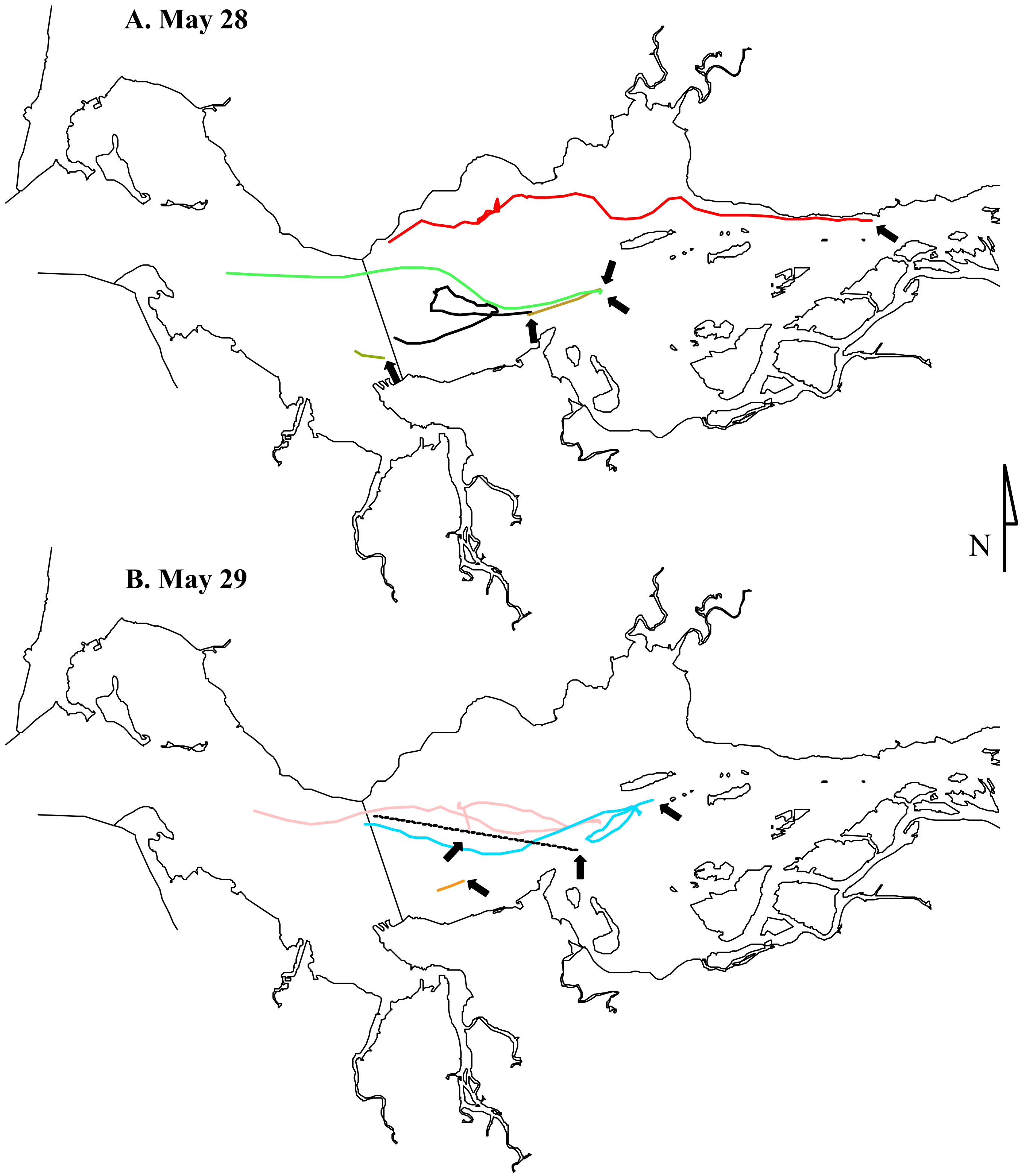


Figure 14. Migration routes of individual barged juvenile spring/summer Chinook through the Columbia River Estuary, based on tracking radio-tagged fish with boats. Release dates for fish were (A) May 28 and (B) May 29, 2004. Different colored lines represent individual fish with an arrow indicating the start of tracking for each fish. Dotted lines are shown when the time between waypoints (locations where fish were detected) was greater than one hour.

The downstream migration rate of fish during different tidal cycles was examined. The rate of movement between GPS waypoints was calculated for all data collected on radio-tagged fish during manual tracking with boats. Results for spring/summer Chinook in 2004 indicated a passive movement with tides (Figure 15).

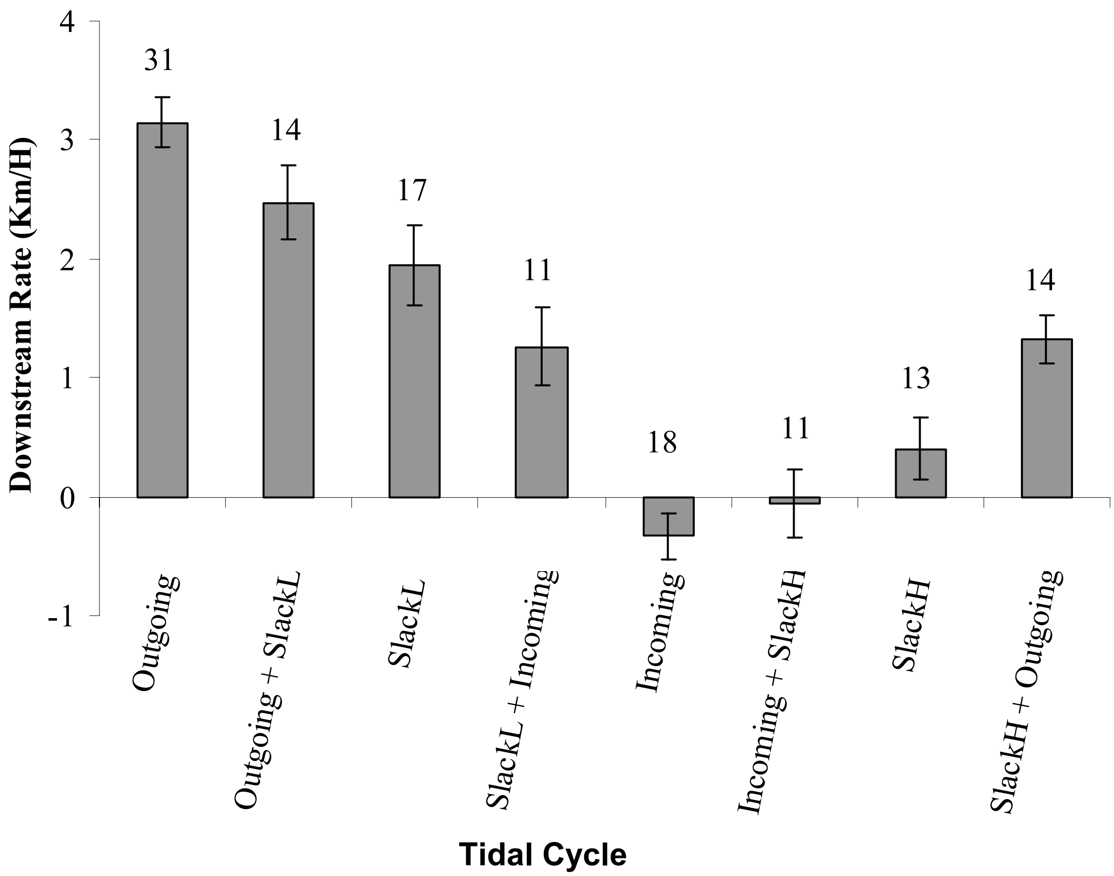


Figure 15. The weighted average downstream rate (with standard error) of juvenile spring/summer Chinook for different tidal cycles, based on tracking radio-tagged fish with boats in 2004. The numbers above bars show the numbers of individual fish that were used to calculate the rate. The x-axis categories which have two tidal cycles listed (i.e. outgoing + slackL) were calculated from waypoints that encompassed part of both cycles. The slackL or slackH refer to a slack period in either a low or high tidal stage.

CORIE modeling

We used both CORIE modeling and actual fish tracks to explain fish movements in the estuary. Given that outmigrants tend to swim near the surface (Birtwell and Kruzynski 1989, Beeman et al. 1999), we co-pared actual fish tracks with CORIE predictions of water particle movement, restricted to 1 m and 3 m depths. For example, Figure 16 shows preliminary CORIE model runs depicting an actual fish track (dashed line) and two “simulated” water particle tracks for particles released near the surface (red), and the other at depth (black).

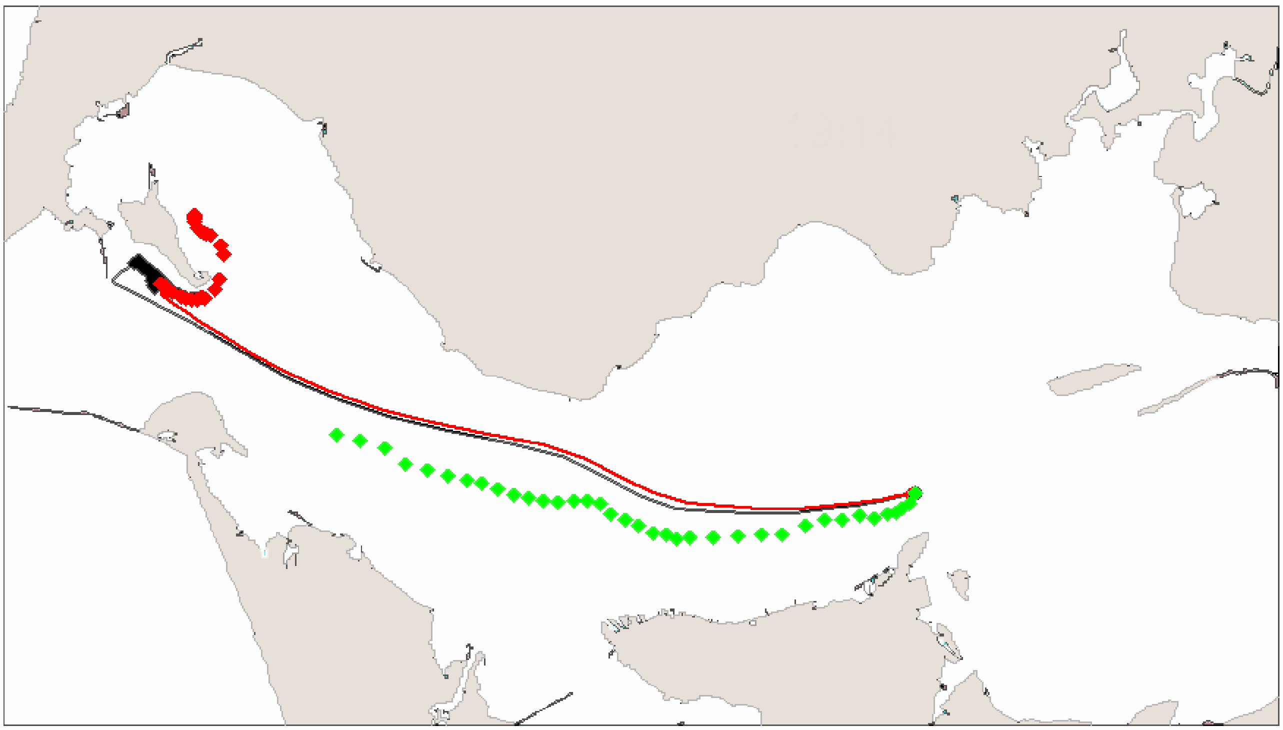


Figure 16. CORIE model depicting simulated water particles at two depths (red and black) and an actual fish track (dashed green line) in the lower Columbia River estuary. Note that the upstream movements reflect a change in the tide, and water particles end up within the vicinity of East Sand Island for this particular fish/particle comparison.

Current analysis of the CORIE modeling is suggestive of a relationship between water velocity and behavior of smolts during the 2002 – 2004 seasons. The model may be a useful tool for evaluating the impact of different hydrological regimes on fish movement (Truelove, unpublished data). The strongest relationship appears to exist during high water velocities ($\geq$ 1 m/s). During these periods, fish movements correspond well with simulated water particle movements, thus their behavior can be classified as passive to the extent that the hydrological regime dominated the movement patterns of outmigrant salmonids in the estuary (Truelove, unpublished data) (Figures 17 and 18). During low water velocities associated with slack tide, the correlation between fish locations and simulated water particle locations were relatively weak and fish behavior was classified as active. During a range of fast and slow water velocities, small periods of active behavior ($\leq$ 30 min) can rapidly lead to large discrepancies between simulated water particle location and fish location, if the water particles are only released once at the beginning of the fish track, particularly for fish tracks > 8 hours. Indeed, over the course of multiple tidal cycles, passive and active swimming behaviors resulted in a difference of several kilometers between the simulated passive drifters and migrating juvenile salmon. Active swimming behavior moved juvenile salmon into distinct estuarine channels not traveled by simulated drifters. Water circulation within the complex network of channels of the Columbia River estuary is dependent upon changes in ocean tides, regulated river discharge, and coastal winds. Furthermore, the velocity and direction of surface currents vary from one channel to the next. Even slight periods of active swimming out of one channel and into another can have powerful effects on the dispersal of juvenile salmonids within the Columbia River estuary (Truelove, unpublished data).

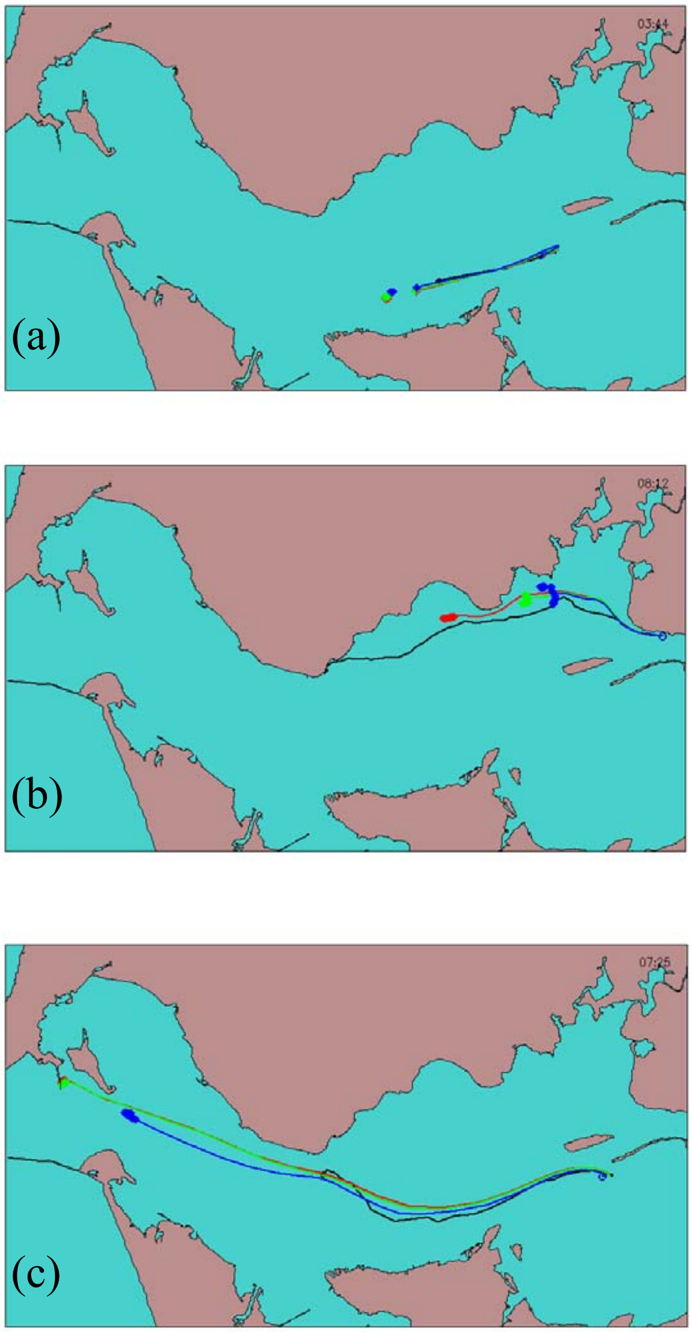


Figure 17. Virtual drifter simulations, 0.1m (red), 1m (green), 3m (blue) with individual fish tracks (black) during ebb tides. Note the passive swimming (drifting) during ebb tides (a) and active swimming with the current during ebb tides (b and c).

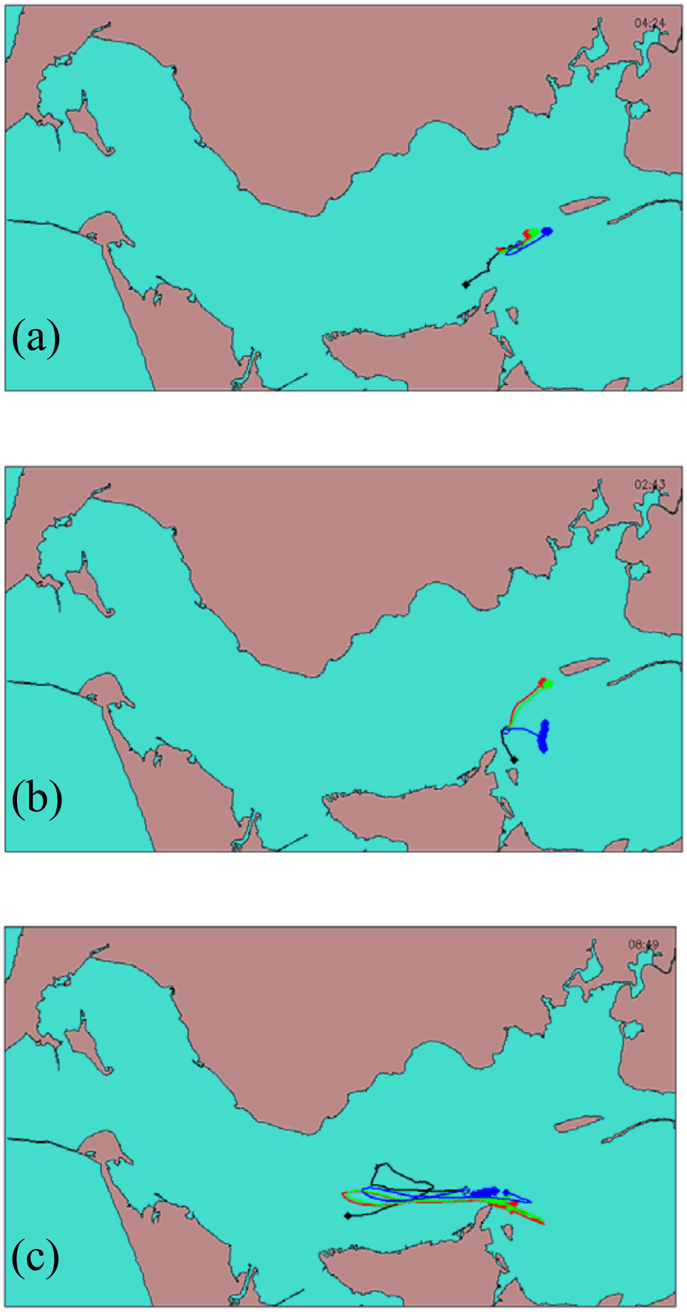


Figure 18. Virtual drifter simulations, 0.1m (red), 1m (green), 3m (blue) with individual fish tracks (black) during flood tides. Note the active swimming against the current during flood tides (a), active swimming across current during flood tide (b), and passive drifting during the flood tide (c).

Changes in both active and passive swimming behavior occurred during changes of tidal phase. Simulated ADCP data from the CORIE model which included tidal height and simulated surface velocities were linked to each geolocation for all individual fish tracks. The results of this analysis were consistent with results of simulated passive drifter experiments (Figures 17 and 18). During the shift from flood to ebb tide both fish rate over ground and particle rate over ground increased (Figure 19). During flood tides simulated passive particle velocities were often equal to (indicative of passive swimming behavior) or greater than fish velocities (indicative of swimming against the current). In contrast during ebb tides fish velocities were often greater than particle velocities (indicative of swimming with the current) or equal to particle velocities. However, during periods of high ebb tide velocities (greater than 2m/s), fish velocities were often slower than particle velocities (Truelove, unpublished data).

Alternative simulations compared fish location to water particle location on a waypoint by waypoint basis to pinpoint the exact time and location that active and passive behaviors occur. This analysis provided an even better fit for data representing actual fish and the simulated water particles. In general, fish movement downstream is quite similar to that of water particles on the outgoing tide. There still tends to be some active downstream migration during low tide. During the incoming or high tidal stages fish tend not to make any progress downstream. This is based on analysis of 62 actual fish tracks, consisting of juvenile spring/summer Chinook, fall Chinook, and steelhead, collected over three years, and CORIE model simulations of water particles during the times that these actual fish tracks were taken.

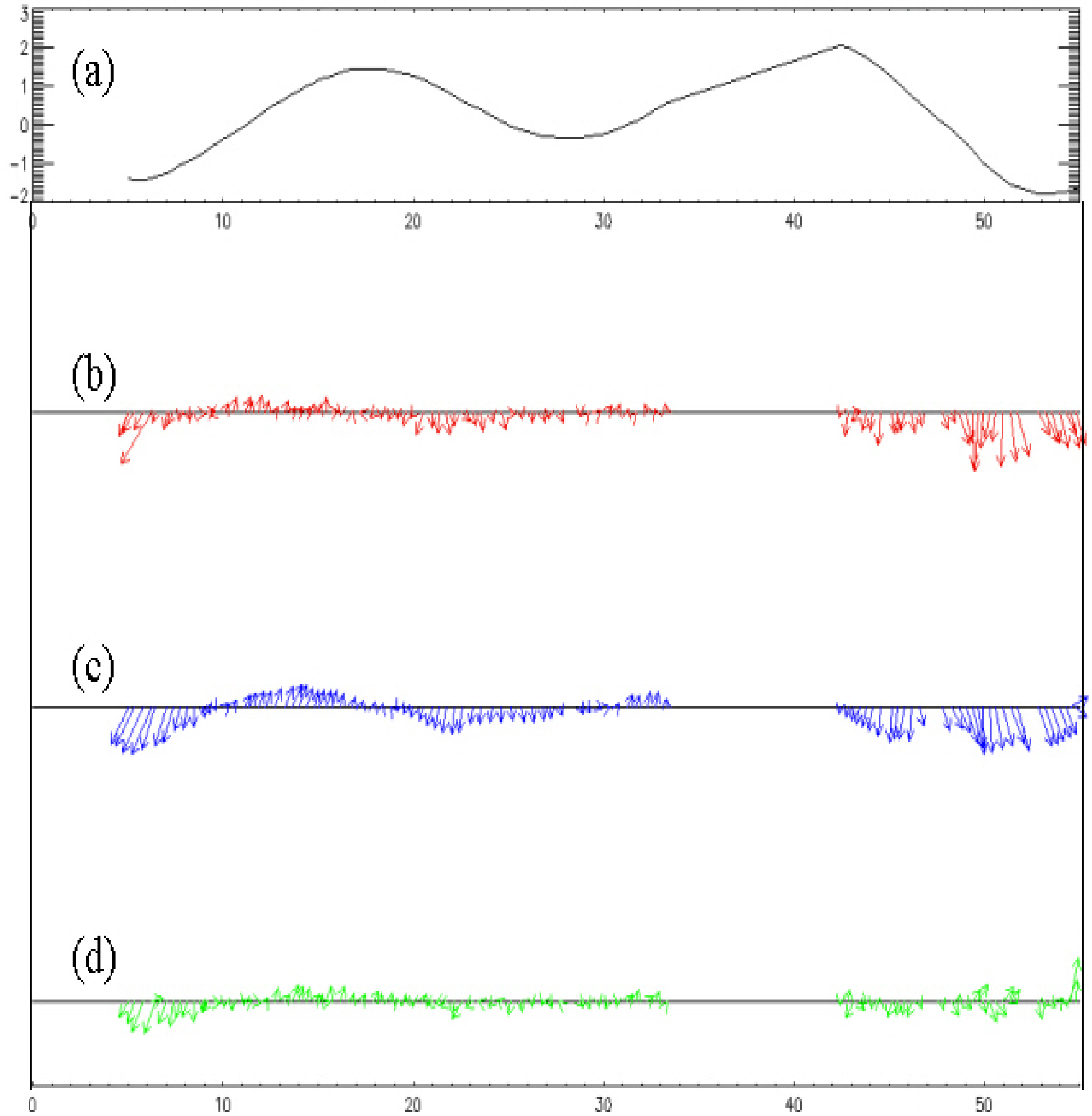


Figure 19. Tidal height (a), fish rate and direction from active tracking (b), passive surface drifter rate and direction from CORIE Model (c), difference in rate and direction between surface drifter location and fish location (d). Arrows indicate the direction and magnitude of velocity in meters/second.

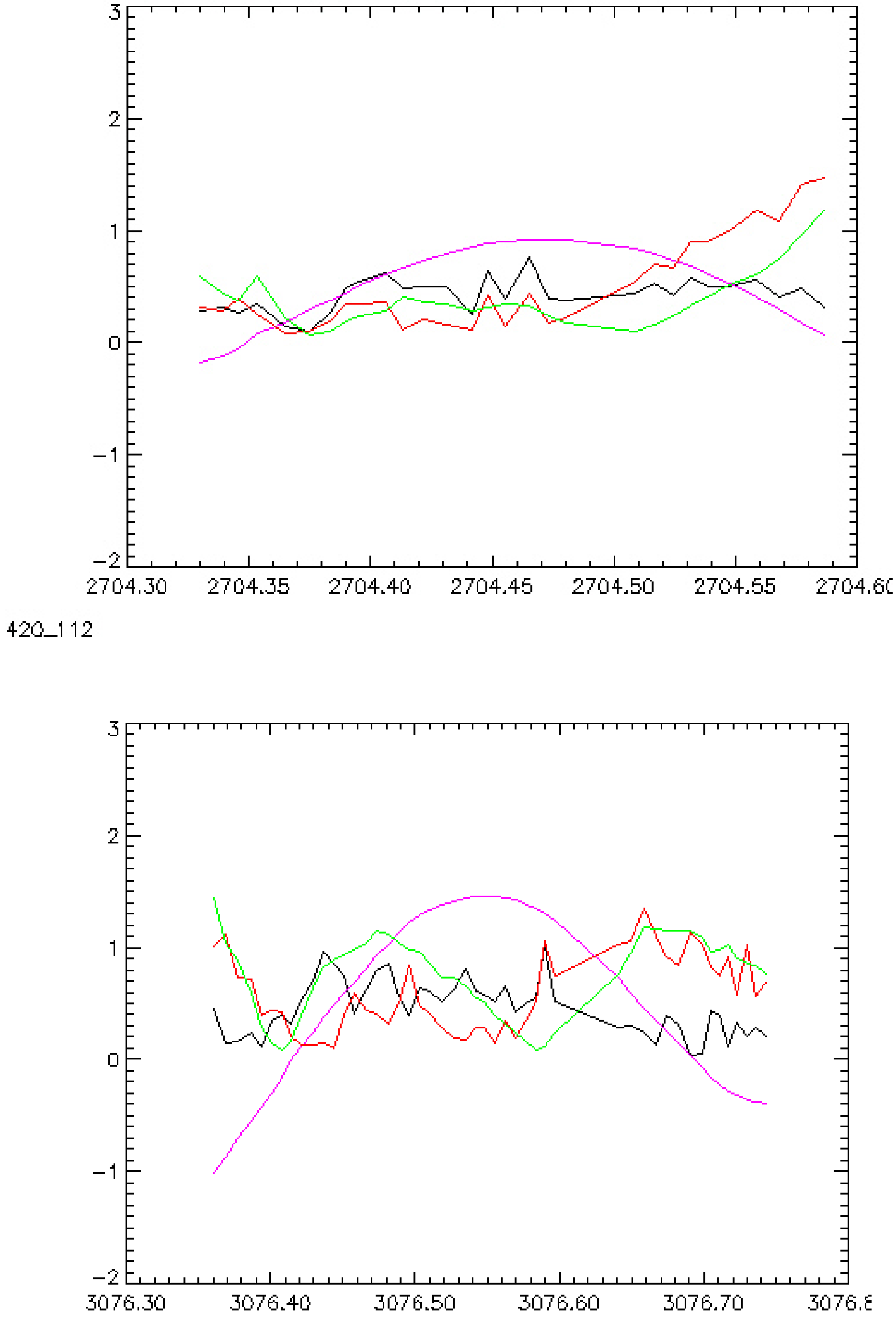


Figure 20. Individual behavior profiles for all geolocations (Δt=10min) during active estuarine tracking for two tidal heights. X-axis (time), Y-axis (meters). Magnitude of fish velocity over ground (m/s) in red, simulated particle velocity over ground (m/s) in green, difference between simulated particle geolocation and fish geolocation (m/s) in black and tidal height (m) in purple.

Vector magnitude and orientation analysis confirmed tidal induced changes in swimming behavior observed in Figures 17 – 19. The direction of movement of juvenile salmon was strongly influenced by the interaction between tidal phase and direction of surface flow (Figures 19 and 20). Vector magnitude (m/s) and orientation of fish geolocations, simulated surface drifter geolocations, and the difference between fish locations and final simulated surface drifters locations were measured in 10 minute intervals for the duration of active tracking in each study fish. During ebb tides juvenile salmon typically migrated in the same direction as the surface currents. The opposite effect was observed during flood tides, where juvenile salmon were typically orientated against the current. However, for all tidal stages, fish rate was generally slower than simulated surface drifters and the greatest differences occurred during high surface velocities (Figure 19d).

The CORIE model provides information on other variables in addition to water velocity and directionality. Temperature and salinity data for any place in the estuary at any desired time could be queried (www.ccalmr.ogi.edu/CORIE/) to correspond to each of our fish tracks. However, presentation of such data is quite problematic because the data are continuous, which leads to both spatial and temporal scaling dilemmas. Due to the agreement between fish migration rate and directionality (i.e., velocity) with modeled water particle velocity, we believe that water movement and depth are the most important variables affecting fish migratory patterns in the estuary.

Ocean migratory patterns

The direction of fish migration in the near-ocean environment was examined. To compare the direction of fish migration in the near-ocean environment the location (north or south side of the array) at which a fish was last detected on a receiver was used; however, it is possible that fish did not exit at the last detection point, but instead could have moved back into the middle of the main shipping channel (where they would not be detected) and exited from there. If all releases are pooled, 88% (275 of 313) of fish were last detected by the receivers on the north side of the array, while only 12% were last detected by receivers on the south side. The actual number of fish that were detected for each release is given in Table 11. The movement and direction of fish for each release is graphically presented in Figures 1 – 3 of Appendix 3. The pattern of exiting towards the north may be due to the hydrodynamics of the near-shore environment and does not signify that the fish continued to move northward. These results are similar to the previous years with steelhead (see “Steelhead” section) in which the majority of fish were last detected on the northern line of receivers. Very few fish crossed over from the north to the south side of the array or vice versa. Once fish exited the array they usually were not detected again. Twenty-one fish were detected a second time on the ocean array more than 6 hours after their first detection (range 6 – 411 h); however this represents only 6.7% of the fish detected on the Ocean Array. It is unknown why these fish resided at the river mouth, but a likely explanation is that the plume from the mouth of the Columbia River was reduced concomitant with lower river flows.

Table 11. The possible ocean migration direction, north or south, of tagged barged spring/summer Chinook in each release and pooled releases in 2004. The migration direction was determined by the last detection location.

	Numbers Detected			Percent Detected	
Release Date	**North**	**South**	**Total**	**North**	**South**
5/3/04	24	7	31	77	23
5/4/04	48	6	54	89	11
5/16/04	32	8	40	80	20
5/18/04	46	3	49	94	6
5/28/04	61	6	67	91	9
5/29/04	64	8	72	89	11
Pooled	275	38	313	88	12

Migratory Success

During 1996-1998, there were no differences in survival estimates between ROR and BRG spring/summer Chinook (Schreck et al. 1996 and 1997; Schreck and Stahl 1998; Jepsen et al., *in preparation*). Overall percentages of tagged fish successfully migrating to the estuary during these years included: 79-92% BRG and 77-97% ROR (1996), 74-97% BRG and 77-91% ROR (1997); 74-100% BRG and 65-96% of ROR fish (1998).

In 2004, the majority of radio-tagged, barged spring/summer Chinook migrated from the release site below BON to the Stella (WA, rkm 89) fixed radio site in the lower Columbia River. Ninety to 96% (range) of all tagged fish in all releases migrated to this site (Figure 21). The majority of radio and acoustic-tagged Chinook also migrated successfully to the upper estuary (Jim Crow Point, rkm 46): 66 - 92% implanted with acoustic transmitters and 82 – 100% of the smolts implanted with radio transmitters migrated successfully to the estuary (Figure 22).

The results of the logistic regression model suggest decreased survival to Jim Crow point (rkm 46) for fish tagged with acoustic transmitters compared to radio-tagged fish (Figure 22; Appendix 2.B.1.). The model also indicates significant differences in survival between and amongst releases (Appendix 2.B.1.).

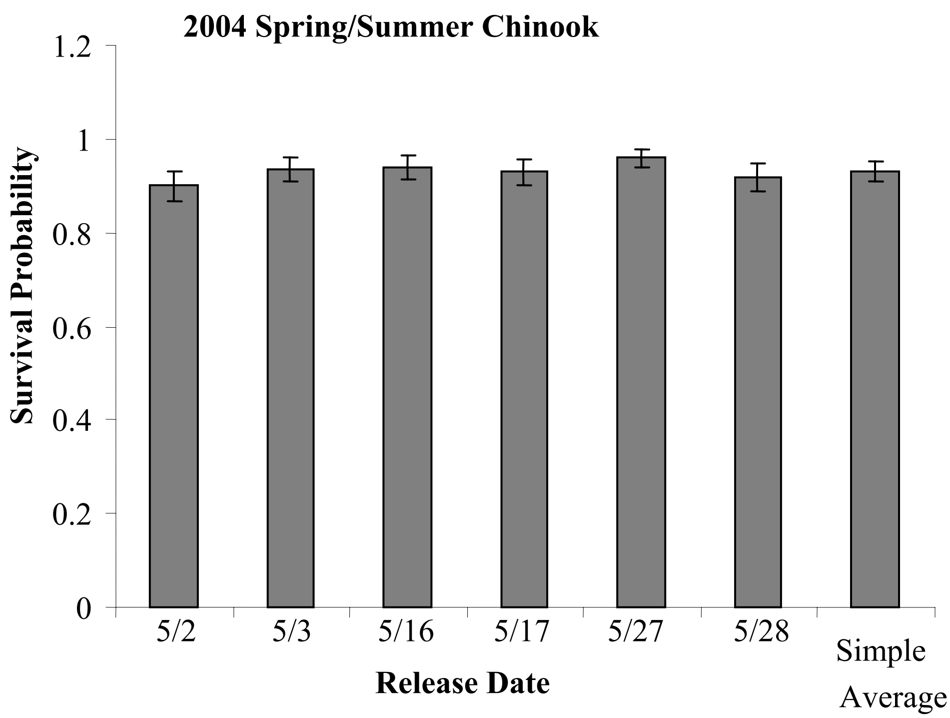


Figure 21. Survival estimates for radio-tagged juvenile spring Chinook from the release location near Bonneville Dam to Stella, WA (rkm 89), in the lower Columbia River in 2004. Error bars on individual release days are the standard error, while those on the simple average are 95% confidence intervals.

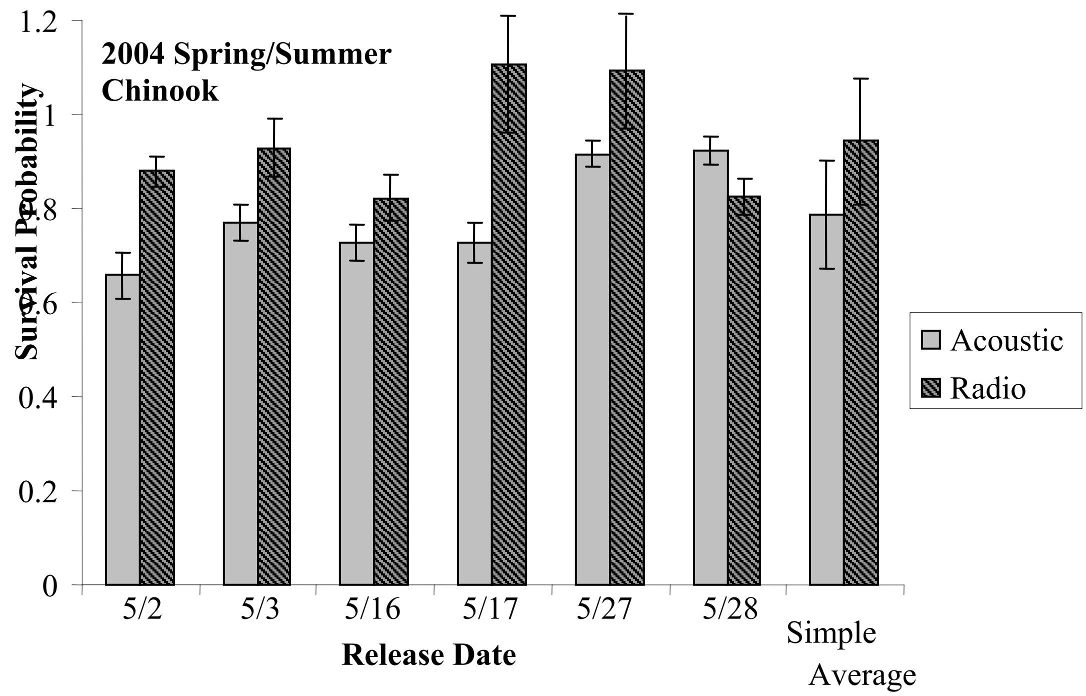


Figure 22. Survival estimates for acoustic and radio-tagged juvenile spring/summer Chinook from the release location near Bonneville Dam to Jim Crow Point (rkm 46) in the upper Columbia River Estuary in 2004. Error bars on individual release days are the standard error, while those on the simple average are 95% confidence intervals.

Survival estimations generated from SURPH do not differ from the simple survival estimates made in previous years' studies (Schreck et al. 2001*a*, 2001*b*, 2001*c*, 2002*a*, 2002*b,* 2003*a*, and 2003*b*). Survival estimates from these previous years were generated from simple arithmetic calculations of fish that were not detected at one site but heard at a downstream site:

[(D*array i* + M)/R]*100

where **D** = number of fish detected at receiver ***array i***,

M = the number of fish missed by array *i*, but detected at receiver array(s) downstream,

and **R** = the number of fish released below Bonneville Dam.

For example, if 100 fish were released at Bonneville Dam (**R**) and 85 of these fish were detected at the Jim Crow Array (**D*array i***), and an additional 5 fish were detected at a receiver array downstream (**M**), then 90 fish were detected at or below this site (**D*array i* + M**). Therefore, 90% of the fish survived to Jim Crow:

$$[(85 + 5)/100]*100 = 90\%$$

There are several potential criticisms of this simple arithmetic calculation. One criticism is that this method only looks at detected fish and some fish may have been missed by all sites. Additionally, sample size is not considered into the survival estimate. To look at this issue, we plotted the simple arithmetic calculation and the SURPH estimate (Figure 23). There is very little discrepancy between these techniques, most likely due to the high efficiencies of the arrays.

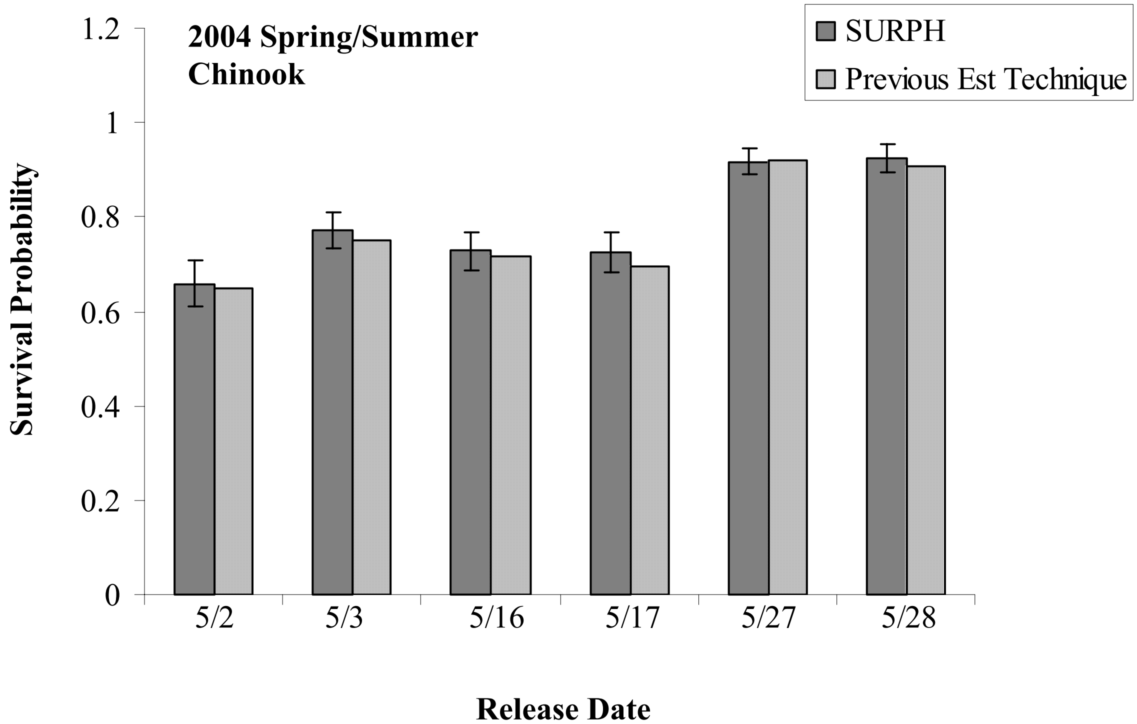


Figure 23. Survival estimates for acoustic-tagged juvenile spring/summer Chinook from the release location near Bonneville Dam to Jim Crow Point (rkm 46) in the upper Columbia River Estuary. SURPH estimates are compared to the calculation method used in previous years, which are the fish detected at the Jim Crow site corrected with known fish that were missed by this site. Error bars on individual release days are the standard error, while those on the simple average are 95% confidence intervals.

In previous years, we presented the proportion of fish detected on the Ocean Array, referred to as an index of survival to the ocean. These detections account for the minimum number of fish entering the ocean; they do not take into account fish that migrated successfully to the ocean but went undetected. In 2004, approximately 30% of fish from the release point were detected on the ocean array in the first four releases; this is similar to the percentage of steelhead detected entering the ocean in previous years (Schreck et al. 2002*b*, 2003*a*) (Figure 24). It is unknown what contributed to the high proportion of detections of spring/summer Chinook in the last two releases.

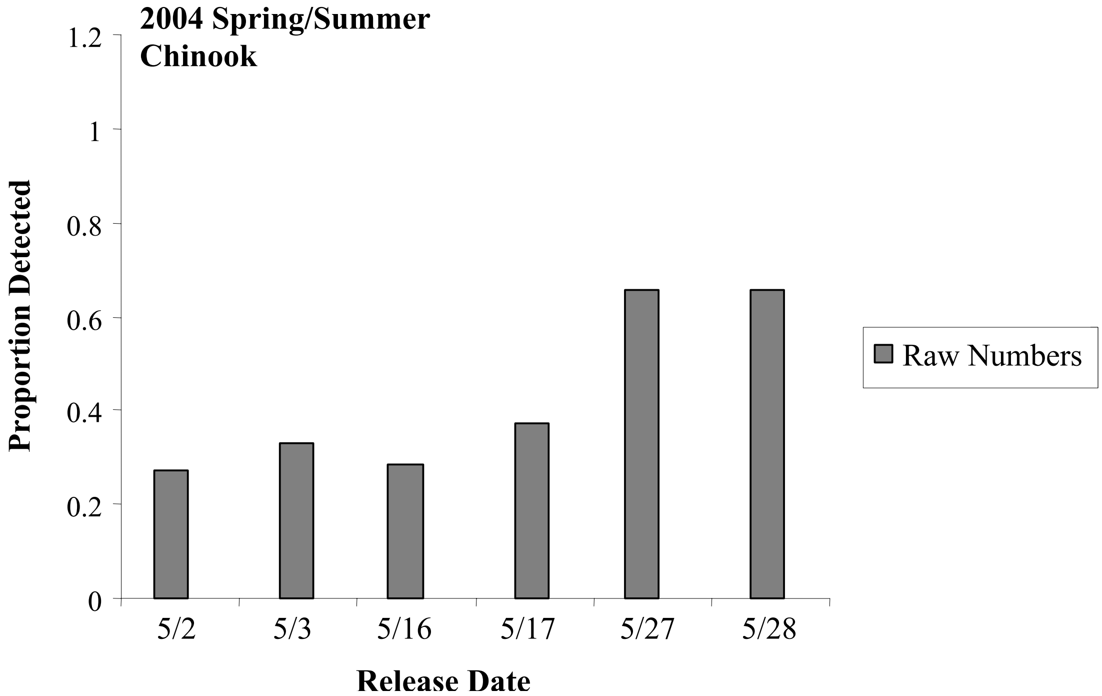


Figure 24. Proportion of detections for acoustic-tagged juvenile spring Chinook from the release location near Bonneville Dam to the mouth of the Columbia River. These proportions are the minimum number of fish detected entering the ocean; they do not take into account fish that migrated successfully to the ocean but went undetected.

The ultimate fate of fish with transmitters that were not detected in the estuary is unknown. All tags were known to be functioning prior to release. It is possible that fish: 1) died after release 2) were taken by predators and their remains deposited out of radio/acoustic range, 3) migrated successfully but went undetected (missed by receivers), or 4) migrated to the estuary after the batteries had failed (> 11 days for radio tags, ~30 days for acoustic tags). Based on detection tests at the transition site in 2001 and 2002, radio tags could be detected to ~ 5.5 m depth at a distance > 400 m. As water depths in the main channel at this location can exceed 25 m, some migrants swimming lower in the water column may have passed the transition site undetected. However, depth tag data on steelhead suggest that most fish travel in reservoirs within the upper ~ 2.4 m of the water column (Beeman et al. 1999). Behavioral assays on juvenile Pacific salmon (*Oncorhynchus spp.*) have determined that fish were biased towards the water surface and avoided waters of depth (Birtwell and Kruzynski 1989). All tags were transmitting after tagging; therefore we assume each tag could be detected after release. If this assumption is false, then the true sample size of observable tagged fish is reduced and the relative proportion of fish reaching the estuary is higher than reported.

Avian Predation

During earlier years (1996-1998), before the Caspian tern (*Sterna caspia*) colony was moved from Rice Island in the middle estuary to East Sand Island in the lower estuary (Roby et al. 2002), 71-85% of the known total seasonal mortalities were caused by avian predators on Rice Island (Tables 12 – 14). ROR fish in 1996 were the only exception, in which the total amount of fish taken by birds was approximately evenly split between Rice and East Sand Islands. There was no obvious and consistent trend between fish size and predation (Tables 12 – 14), suggesting that the relationship between fish size and predation rates is complex and not completely understood.

The overall percentage per year of spring/summer Chinook taken by avian predators ranged between 0% and 40% during earlier years (1996-1998), and was comparatively small for 2004 (7%). The reasons for these differences are unclear; however, our current estimate of 7% more closely approximates PIT tag data presented by Ryan et al. (2003), who reported an estimated minimum percentage of 2.3-3.5% for juvenile Chinook salmon. Glabek et al. (2003) reported that detection efficiencies of PIT tags on the piscivorous bird colonies ranged from 45% to 95%. Therefore, it is possible that Ryan et al. (2003) detected less than half of the tags present; in this case their estimates would more closely approximate ours. Additionally, radio tags can be detected at locations where PIT tags cannot (i.e., rugged terrain or water along periphery of island), which may have accounted for differences in detection. Finally, the larger radio tags may have increased susceptibility to predation.

There was no evidence that barged or ROR fish experienced mortality in higher proportions than the other for any of the earlier years that were individually examined (1996-1998) (Appendix 2.C.1. to 2.C.3.).

In 2004, avian depredation was relatively low in comparison to 1996-1998. A total of 2% of all radio-tagged fish released in 2004 were detected on the Caspian tern colony, compared with 5% on the double-crested cormorant (*Phalacrocorax auritus*) colony; a total of 7% (Table 15). There was no consistent trend between fish size and predation (Table 15), suggesting that the relationship between fish size and predation rates is complex and not completely understood.

In 2004, there was a significant difference in mortality of barged spring/summer Chinook, with respect to outmigration period. The highest mortality occurred during the middle period compared to both the early and late periods (which were comparable). (Appendix 2.C.4.).

Table 12. Percentages of all radio-tagged spring/summer Chinook released and subsequently detected on the bird colonies of Rice Island in the middle estuary and East Sand Island (ESI) in the lower estuary for BRG and ROR fish in 1996. Tags were detected by plane transects. Average fork lengths (FL) (and ranges) are for Rice Island mortalities, East Sand Island mortalities, and overall mortalities (Rice + East Sand Islands).

1996 BRG							
Release	**Number Released**	**% Rice**	**FL for Rice**	**% ESI**	**FL for ESI**	**% of Total**	**FL**
4/21	38	3	132	3	164	**5**	148 (132-164)
4/29	38	13	135 (131-140)	3	130	**16**	134 (130-140)
5/5	38	8	137 (126-150)	0	---	**8**	137 (126-150)
5/11	39	8	142 (135-147)	5	139 (135-142)	**13**	140 (135-147)
5/19	35	20	137 (127-150)	3	144	**23**	138 (127-150)
5/29	38	13	144 (136-158)	8	148 (144-152)	**21**	145 (136-158)
6/10	0	**---**	**---**	**---**	**---**	**---**	---
Overall	**226**	**11**	133 (126-158)	**4**	145	**14**	140 (126-158)

1996 ROR							
Release	**Number Released**	**% Rice**	**FL for Rice**	**% ESI**	**FL for ESI**	**% of Total**	**FL**
4/21	0	---	---	---	---	**---**	---
4/29	0	---	---	---	---	**---**	---
5/5	0	---	---	---	---	**---**	---
5/11	32	8	143 (131-158)	5	163 (126-180)	**25**	153 (126-180)
5/19	12	20	142 (132-151)	3	---	**17**	142 (132-151)
5/29	38	13	165 (146-177)	8	148 (130-173)	**18**	157 (130-177)
6/10	32	28	159 (144-193)	0	---	**28**	159 (144-193)
Overall	**114**	**12**	155 (131-193)	**11**	156 (126-180)	**23**	155 (126-193)

Table 13. Percentages of all radio-tagged spring/summer Chinook released and subsequently detected on the bird colonies of Rice Island in the middle estuary and East Sand Island (ESI) in the lower estuary for BRG and ROR fish in 1997. Tags were detected by plane transects and boat tracking. Average fork lengths (FL) (and ranges) are for Rice Island mortalities, East Sand Island mortalities, and overall mortalities (Rice + East Sand Islands).

1997 BRG

Release	Number Released	% Rice	FL for Rice	% ESI	FL for ESI	% of Total	FL
4/22	30	0	---	0	---	**0**	---
4/30	30	3	132	0	---	**3**	132
5/8	36	14	149 (134-167)	6	137	**19**	146 (134-167)
5/16	34	6	153 (144-161)	9	147 (141-155)	**15**	149 (141-161)
5/24	39	10	147 (133-168)	3	180	**13**	153 (133-180)
6/1	38	21	157 (131-197)	5	174 (173-175)	**26**	160 (131-197)
Overall	**207**	**10**	151 (131-197)	**3**	155 (137-175)	**14**	153 (131-197)

1997 ROR

Release	Rice Island	% Rice	FL for Rice	% ESI	FL for ESI	% of Total	FL
4/22	0	0	---	0	---	**0**	---
4/30	0	0	---	0	---	**0**	---
5/8	0	0	---	0	---	**0**	---
5/16	34	12	167 (157-189)	6	176 (173-178)	**18**	170 (157-189)
5/24	30	23	156 (128-187)	0	---	**23**	156 (128-187)
6/1	31	10	172 (150-190)	0	---	**10**	172 (150-190)
Overall	**95**	**15**	163 (128-190)	**2**	176 (173-178)	**17**	164 (128-190)

Table 14. Percentages of all radio-tagged spring/summer Chinook released and subsequently detected on the bird colonies of Rice Island in the middle estuary and East Sand Island (ESI) in the lower estuary for BRG and ROR fish in 1998. Tags were detected by plane transects and boat tracking. Average fork lengths (FL) (and ranges) are for Rice Island mortalities, East Sand Island mortalities, and overall mortalities (Rice + East Sand Islands).

1998 BRG

Release	Number Released	% Rice	FL for Rice	% ESI	FL for ESI	% of Total	FL
4/29	24	25	137 (127-148)	0	---	**25**	137 (127-148)
5/2	20	0	---	10	135 (134-135)	**10**	135 (134-135)
5/7	26	12	146 (141-150)	8	139 (135-142)	**19**	143 (141-150)
5/10	19	5	142	5	148	**11**	145 (142-148)
5/15	24	17	157 (147-179)	0	---	**17**	157 (147-179)
5/18	19	5	142	0	---	**5**	142
5/23	20	10	162 (160-163)	5	153	**15**	159 (153-163)
5/24	25	16	146 (143-151)	4	128	**20**	142 (128-151)
5/30	14	0	---	0	---	**0**	---
6/1	16	19	152 (143-166)	0	---	**19**	152 (143-166)
Overall	**207**	**12**	147 (127-179)	**3**	139 (128-153)	**15**	145 (127-179)

1998 ROR

Release	Number Released	% Rice	FL for Rice	% ESI	FL for ESI	% of Total	FL
4/29	0	---	---	---	---	---	
5/2	0	---	---	---	---	---	
5/7	0	---	---	---	---	---	
5/10	0	---	---	---	---	---	
5/15	25	4	159	0	---	**4**	159
5/18	18	28	145 (133-158)	0	---	**28**	145 (133-158)
5/23	25	8	175 (155-195)	12	154 (135-170)	**20**	163 (135-195)
5/24	20	35	152 (145-160)	0	---	**35**	152 (145-160)
5/30	24	4	181	4	141	**8**	161 (141-181)
6/1	15	33	173 (151-197)	7	126	**40**	165 (126-197)
Overall	**127**	**17**	159 (133-197)	**4**	146 (126-170)	**20**	157 (126-197)

Table 15. Percentages of all radio-tagged spring/summer Chinook released and subsequently detected on the bird colonies on East Sand Island (ESI) in the lower estuary for BRG fish in 2004. Tags were detected either by boat tracking or by one of two fixed radio stations, one on the eastern part of the island, and one on the western part. Average fork lengths (and ranges) are for the East Sand Island mortalities.

2004 BRG			
Release	**Number Released**	**% ESI**	**FL**
5/5	99	**6**	159 (139-176)
5/6	101	**2**	170 (162-178)
5/19	100	**12**	152 (141-173)
5/20	99	**15**	148 (140-163)
5/30	97	**5**	145 (138-157)
5/31	98	**2**	144 (137-151)
Overall	**594**	**7**	151 (137-178)

Effects of Behavior on Survival

As mentioned previously, there were several migration patterns in the upper estuary. Median time from the Jim Crow Array to the Astoria Bridge Array for fish using the main shipping channel was 16.5 h, while the median for those using the North Rice Island route was 21.0 h (Table 16). This time difference may have affected survival in the estuary. Fish using the North Rice Island route took 4.5 h longer to migrate than those using the main shipping channel, possibly increasing vulnerability to predators through increased exposure time. However, this would depend on the numbers of predators in a specific area. Due to the small numbers of fish using these backwater routes, it is difficult to make conclusions on the effects of these routes on vulnerability to predators.

Table 16. The length of time for spring/summer Chinook to migrate from the last detection at the Jim Crow Array to the initial detection at the Astoria Bridge Array (~ 25 km) for four upper estuary migration routes in 2004. A count of the number of individuals included in the median, minimum, and maximum hours to migrate for pooled releases.

Route	Count	Median	Minimum	Maximum
Main Shipping Channel	161	16.5	5.2	699.2
North Rice Island	45	21.0	6.4	52.6
Snag Island	10	15.8	13.6	62.0
Seal Island	2	22.0	20.9	23.1

A route effect was derived from the acoustic data collected at the Astoria Bridge Array. In general, fish used one of three main routes when passing under the Astoria Bridge, passing this area: 1) in the main shipping channel (OR), 2) the northern channel (WA) or 3) through a complex of smaller channels in the center of the river. If the acoustic releases are pooled, 59% of barged fish used the Washington channel, 23% used the middle channel, and 18% used the Oregon channel (Table 17). This is a larger percentage using the Washington channel compared to steelhead in 2002 and 2003 (Schreck et al. 2002*b* and 2003*a*; see section on "Steelhead"). This is probably due to larger numbers using the North Rice Island route in the upper estuary (refer back to Figure 11). The subsequent detections of these fish on the Ocean Array may represent an index of their relative survival when using these routes. Unlike previous years (2002 and 2003) with steelhead, a higher percentage of the fish using the Washington channel were subsequently detected on the Ocean Array, possibly suggesting higher survival on the Washington side (all releases pooled). However the difference is small and may be due to unequal sample sizes and variable survival among releases.

Table 17. The number of individual spring/summer Chinook detected for the three large-scale migration patterns in the estuary for each release and for all releases (pooled). The number of those fish that were subsequently detected on the Ocean Array and the corresponding percentages of channel use and subsequent detections on the Ocean Array.

Release Date	Route	# of individual fish detected	# of those fish subsequently detected on Ocean Array		% fish using each route	% subsequently detected on Ocean Array
5/3/2004	WA Channel	24	17	WA Channel	57	71
	Mid Channel	11	6	Mid Channel	26	55
	OR Channel	7	4	OR Channel	17	57
5/4/2004	WA Channel	33	19	WA Channel	47	58
	Mid Channel	19	15	Mid Channel	27	79
	OR Channel	18	8	OR Channel	26	44
5/16/2004	WA Channel	38	26	WA Channel	58	68
	Mid Channel	11	7	Mid Channel	17	64
	OR Channel	17	6	OR Channel	26	35
5/18/2004	WA Channel	38	29	WA Channel	62	76
	Mid Channel	11	8	Mid Channel	18	73
	OR Channel	12	11	OR Channel	20	92
5/28/2004	WA Channel	54	38	WA Channel	64	70
	Mid Channel	23	18	Mid Channel	27	78
	OR Channel	7	6	OR Channel	8	86
5/29/2004	WA Channel	53	41	WA Channel	64	77
	Mid Channel	19	15	Mid Channel	23	79
	OR Channel	11	7	OR Channel	13	64
Pooled	WA Channel	240	170	WA Channel	59	71
	Mid Channel	94	69	Mid Channel	23	73
	OR Channel	72	42	OR Channel	18	58

Fish Size

The size distribution of our tagged fish was positively skewed in 2004, due to tagging requirements (i.e., collecting fish large enough to hold a tag) (Figure 25). However, other researchers have experienced similar problems, as they have also reported positively skewed distributions in their telemetry-tagged fish (e.g., Hockersmith et al. 2003; Perry et al. 2003; Plumb et al. 2004). Fish size data and the number of juvenile spring/summer Chinook tagged and released are summarized for each release date and each tag type in Table 18. With the exception of the first release, fish size was comparable between the two tag types (Table 18, Figure 25). In 2004, radio-tagged fish mass averaged 34.8 g (±0.3 SEM; N = 594), compared with 35.9 g (±0.3; N = 763) for acoustically-tagged fish. These sizes were within the range of 1996-1998 data for radio-tagged spring/summer

Chinook (1996, barged: 30.0 g [±0.5; N = 224], ROR: 36.3 g [±1.1; N = 112]; 1997, barged: 37.6 g [±0.9; N = 210], ROR: 38.9 g [±1.3; N = 97]; 1998, barged: 32.5 g [±0.5; N = 207], ROR: 40.7 g [±1.2; N = 127]. It is interesting to note that sizes of our tagged fish are underrepresented in both the lower and upper size ranges of spring/summer Chinook passing LGR (Figure 25).

During 1996-1998 in general ROR spring/summer Chinook were longer than their BRG counterparts, whereas BRG fish were heavier for a given fork length (Schreck et al. 1996 and 1997; Schreck and Stahl 1998; Jepsen et al., *in preparation*).

Table 18. Summary of fish size data for juvenile spring/summer Chinook that were tagged at the Lower Granite juvenile collection facility in 2004 (BRG group). N values are number of tagged fish released. Means of fork length (mm, FL) and weight (grams, WT) are given with the corresponding standard error in parenthesis. The condition factor, K, is $Wt/(FL^3)*10^5$. *This date was the actual date the fish were released. Throughout the rest of the report, one day is added to this release date for simplicity.

release	Tag Type	release date	Wt (SEM)	FL (SEM)	K (SEM)	N
1	Acoustic	3-May	44.5 (1.1)	162 (1.3)	1.03 (0.01)	117
2	Acoustic	4-May	38.6 (0.8)	155.5 (0.9)	1.01 (0.00)	164
3	Radio	5-May	37.8 (0.9)	154.7 (1.0)	1.01 (0.01)	99
4	Radio	6-May	38.2 (0.9)	154.7 (1.2)	1.02 (0.01)	101
5	Acoustic	16-May	33.1 (0.4)	147.7 (0.5)	1.02 (0.01)	141
6	Acoustic	18-May	32.4 (0.3)	146.5 (0.5)	1.03 (0.01)	132
7	Radio	19-May	33.1 (0.4)	148.3 (0.6)	1.01 (0.01)	100
8	Radio	20-May	33.1 (0.5)	147.1 (0.6)	1.04 (0.01)	99
9	Acoustic	28-May	33.1 (0.4)	147.7 (0.7)	1.03 (0.01)	102
10	Acoustic	29-May	33.3 (0.5)	148.2 (0.7)	1.02 (0.01)	110
11	Radio	30-May	33.7 (0.4)	149.2 (0.6)	1.01 (0.01)	97
12	Radio	30-May*	32.9 (0.4)	148.5 (0.6)	1.00 (0.01)	98

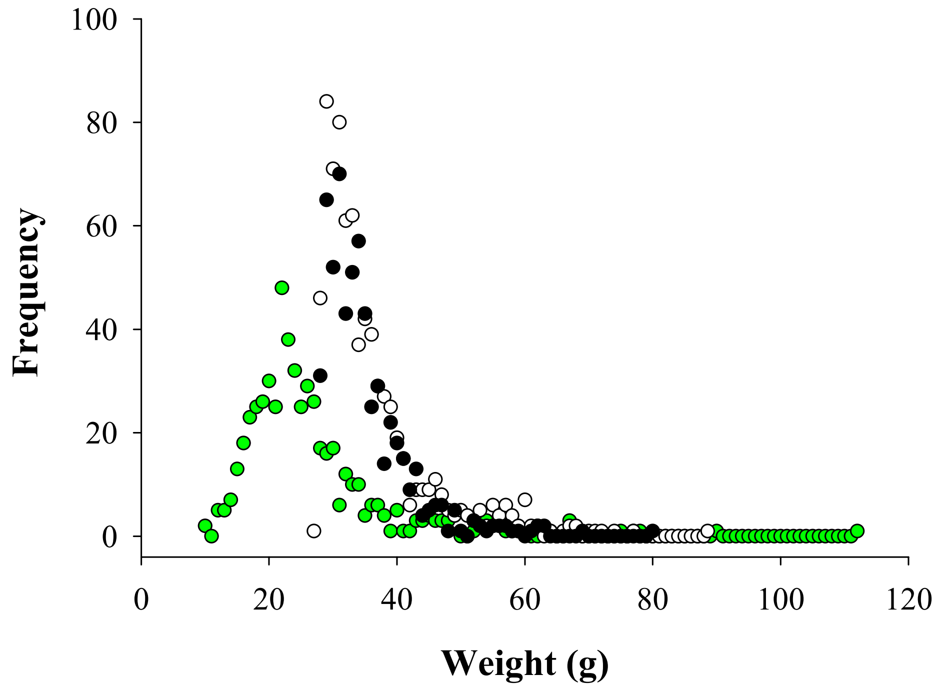


Figure 25. Size frequency distribution of spring/summer Chinook salmon occurring in the LGR Smolt Monitoring Sample operated by WDFW (green circles) and of acoustic- (white circles) and radio-tagged fish (dark circles) for 2004.

Fish Condition

The following is a brief description of physiological findings relative to assessing fish condition or fitness in past year's studies. More specific details on the collection of fish, laboratory analyses, experimental design, and statistical analysis can be found in Congleton et al. (1996), and Schreck et al. (1998). The following bullets represent the main findings and conclusions during the specified year.

1996

* During the peak of the outmigration, it appeared likely that yearling Chinook were moderately to highly stressed at the time of release, as indicated by increased plasma cortisol levels (an indicator of stress). Much of the variation in plasma cortisol levels could not be explained by increased barge loading density.

1998

* Pre-barged fish collected at LGR had significantly higher levels of plasma cortisol than post-barged and/or ROR fish collected at BON, (which were not different than each other, on four of ten release dates). Several groups of barged and ROR fish were stressed after transport or dam passage, respectively.
* Pre-barged fish were significantly less smolted than post-barged or ROR fish, suggesting that smoltification occurred during river passage and barge transit. However, preliminary information based on gill Na^+/K^+ ATPase (ATPase) and bacterial kidney disease (BKD) levels suggested that smolts taken by avian predators in the estuary tended (though not significantly so) to be less smolted and more diseased than other fish collected upstream. The ATPase levels of fish sampled from Caspian terns was likely not affected between the time they were captured by the birds and sampled by Dr. Roby. The fish were often still living or recently dead so there would be no difference from more routine collections where fish are anesthetized before sampling.
* Prevalence of bacterial kidney disease was low throughout the season, with >86% of all fish having zero or barely detectable levels of infection.

Overview

Plasma cortisol levels were not indicative of barge loading density, however, Chinook that are co-transported with steelhead are clearly stressed (Kelsey et al. 2002). BKD levels were low throughout the 1998 season. Adverse fish condition appeared to render smolts more vulnerable to avian predation, based on low ATPase levels and high incidence of BKD infection, although these factors should be examined in more detail to determine if these factors are significant.

Earlier work by Schreck et al. (1994 and 1995) revealed that stress levels, as measured by cortisol concentrations, generally increased as spring/summer Chinook transitioned through the collection system. We found that spring/summer Chinook were able to recover from the stress of dam passage within the barge during the early part of the run, but not during the middle or late periods of the run. The inability of these fish to recover in the barge during the middle and late periods of the outmigration season are likely a reflection of high loading densities in the barge and increased smoltification levels, which compromise the ability of the fish to handle stress, as well as loading with steelhead during the end of the run (Schreck et al. 1995; Kelsey et al. 2002).

FALL CHINOOK

This section and the next (steelhead) will review our findings of previous years' data and provide SURPH estimates of survival. The details of these studies have been reported in the annual reports cited below.

Migratory Rates and Patterns

In-river migratory rate

ROR and BRG fall Chinook had similar migration rates to rkm 89 (Stella, WA) (Figure 26). Variation in migration rates of BRG fish were more easily explained by river flow. However, migration rates within paired releases (ROR, BRG treatments) had no obvious effect on the proportion of fish detected to this transition site (rkm 89) (Jepsen et al., *in preparation*).

The large variations in migration times from the current barge release site to the estuary indicates that fall Chinook do not reach the estuary as one distinct group of fish (Schreck et al. 2002*a* and 2003*b*).

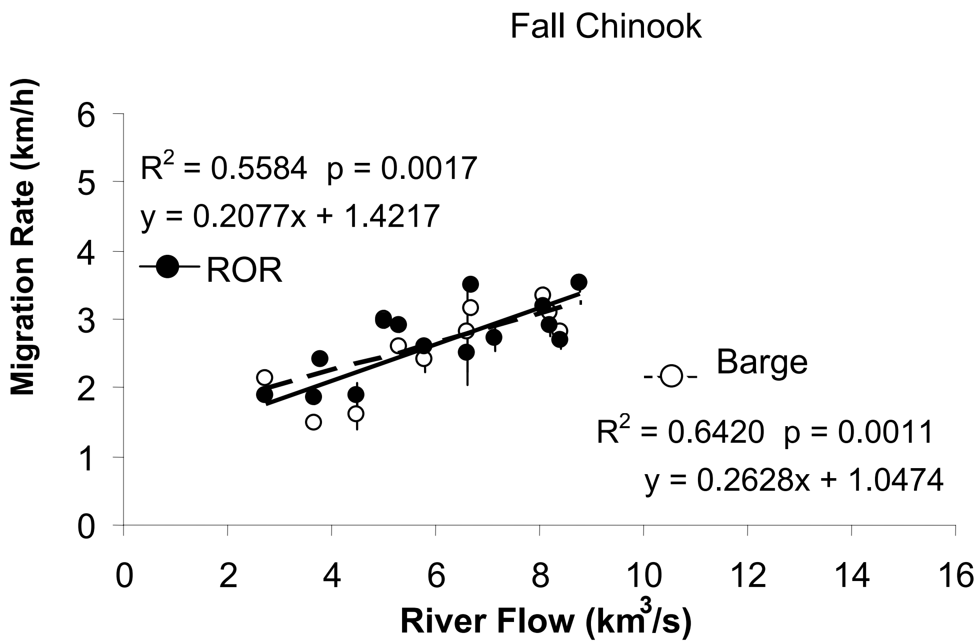


Figure 26. Average river flow from Bonneville Dam (24 hours post-release) regressed against average migration rate of fall Chinook (individual releases) during 2000-2003, from the release site below Bonneville Dam to the fixed radio receiver site near Stella, WA (rkm 89).

Estuarine migratory patterns and rates

The patterns of use in the upper estuary channels (from acoustic monitoring) for fall Chinook are unknown, since the small size of these fish prevented us from using larger acoustic tags. However, we did collect much information on the patterns of use in the mid-estuary from radio data. Fish were tracked by boat in the estuary as previously described for spring/summer Chinook. The graphical presentation of these tracks will not be included in this summary but can be found in the Schreck et al. reports for the corresponding years. In general, fish used similar routes within the mid-estuary in their migration downstream to that of spring/summer Chinook (refer back to Figures 12-14) and steelhead. We could detect no obvious differences between BRG and ROR fish in their use of these channels. There were only very minor differences in the estuarine downstream rates as related to spring/summer Chinook (Figure 27).

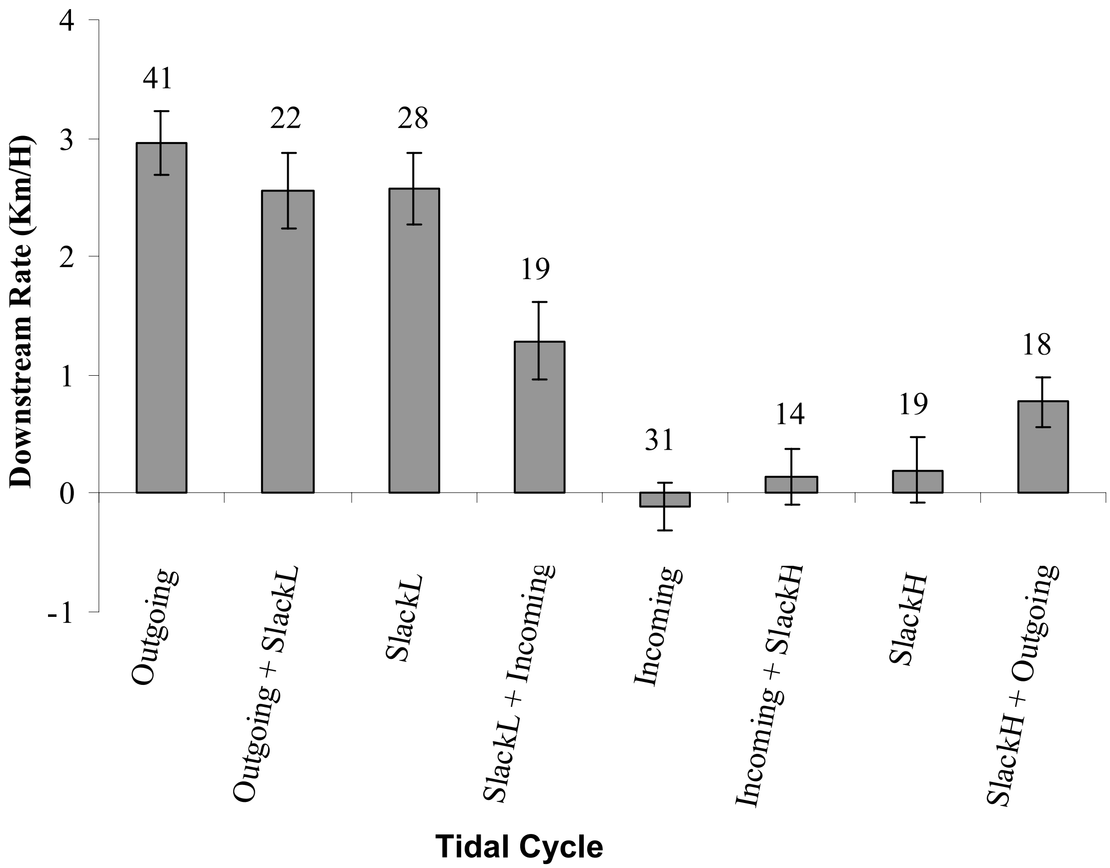


Figure 27. The weighted average downstream migration rate (with standard error) of juvenile fall Chinook for different tidal cycles, based on tracking radio-tagged fish with boats in 2002 and 2003. The numbers above bars show the numbers of individual fish that were used to calculate the rate. The x-axis categories which have two tidal cycles listed (i.e. outgoing + slackL) were calculated from waypoints that encompassed part of both cycles. The slackL or slackH refer to a slack period in either a low or high tidal stage.

Migratory Success

Radio-tagged ROR fall Chinook fared better than their barged counterparts during all releases in 2002 (Figure 28; Appendix 2.B.2.), and in the last four releases in 2003 (Figure 29; Appendix 2.B.3.). Furthermore, it is evident that barged fish survived in much lower proportions as the season continued (Figures 28 and 29), which may be a reflection of the increasing water temperatures these fish experienced during their migration to LGR. If this is the case, then the quality of barged fall Chinook is poor, and survival estimates in the estuary can be expected to be poor as well. A logistic regression of the 2002 data was also suggestive of a direct, positive influence of river flows on survival (Appendix 2.B.2.).

With the cessation of spill at most Snake River dams during the summer months, thermal stratification in the Snake River or at the confluence of the Snake and Columbia Rivers may be apparent. Temperature monitoring in barge holds supports this hypothesis in the McNary and John Day reservoirs, especially when air temperature is relatively warm and wind speeds are below 6 kph (Hoffarth 2000). Hoffarth (2000) reported that water temperature in the barge holds increased by an average of 2.9ºF in the McNary reservoir (approximately 5 h transit time) and 3.3ºF in the John Day reservoir (approximately 10 h transit time) during June-July. The most extreme temperature changes observed were a 5.8ºF increase between the McNary tailrace and the John Day forebay and a 4.6ºF decrease between the John Day forebay and tailrace (Hoffarth 2000). Large temperature changes such as these may account for the relatively poor survival estimates of BRG fall Chinook in the lower Columbia River during June-July (Figures 28-30); these fish may be experiencing delayed mortality following release from barges. ROR fish could have the advantage over BRG fish in these situations because they could avoid warm surface water by seeking cooler temperatures in deeper water.

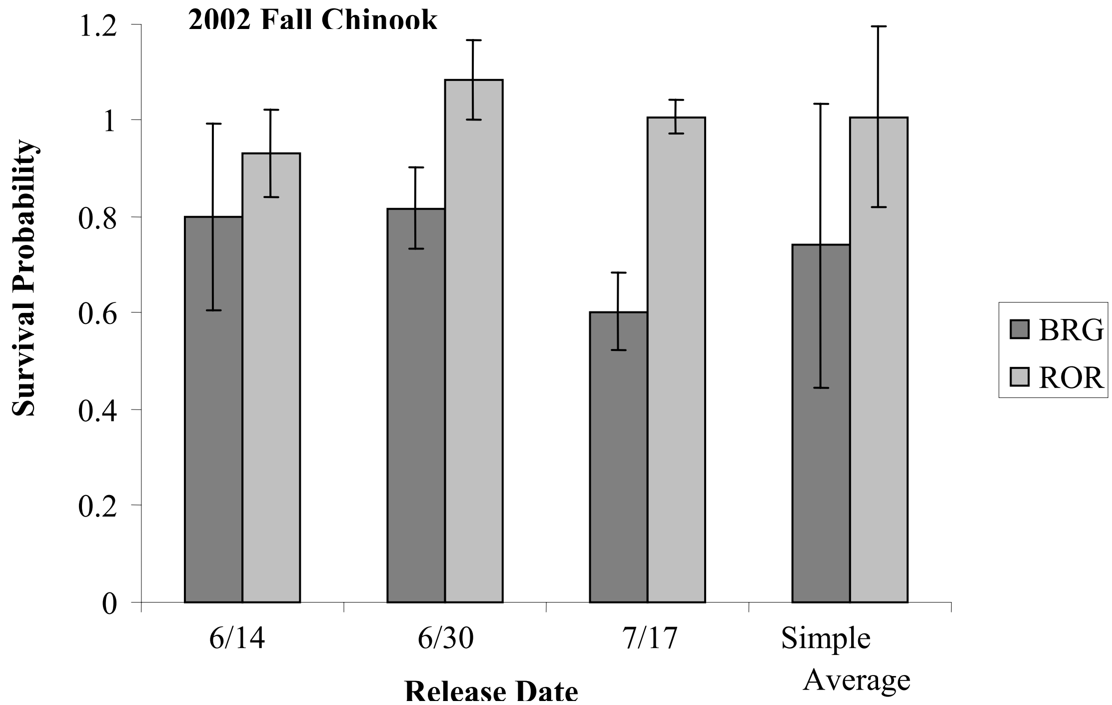


Figure 28. SURPH survival estimates for radio-tagged barged (BRG) and run-of-the-river (ROR) juvenile fall Chinook from the release location near Bonneville Dam to Stella, WA (rkm 89), in the lower Columbia River. Error bars on individual release days are the standard error, while those on the simple average are 95% confidence intervals.

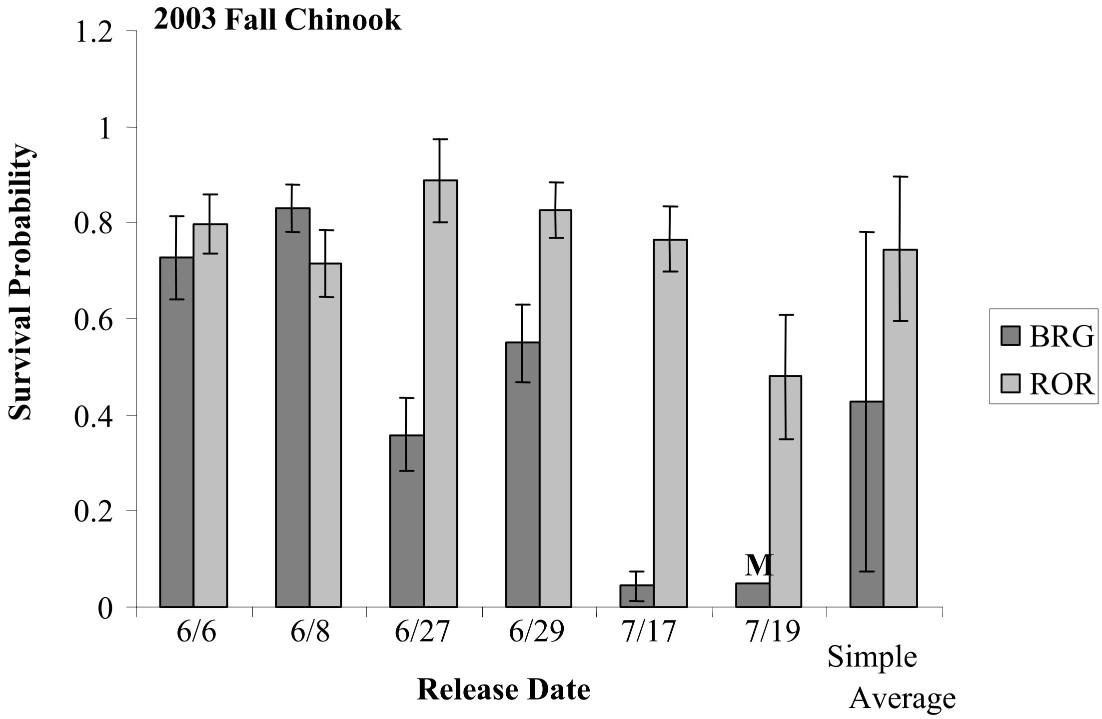


Figure 29. Survival estimates for radio-tagged barged (BRG) and run-of-the-river (ROR) juvenile fall Chinook from the release location near Bonneville Dam to Stella, WA (rkm 89), in the lower Columbia River for 2003. When SURPH estimates were not available (due to extremely high or low detection probabilities), simple arithmetic was used to approximate these estimates (denoted by 'M') Error bars on individual release days are the standard error, while those on the simple average are 95% confidence intervals.

Radio-tagged ROR fall Chinook appeared to survive in higher proportions than their barged counterparts to Jim Crow point (rkm 46) throughout the mid- to late migration periods, though this difference was not statistically significant (Appendix 2.B.4.). However, there was a significant effect of release day, release period, and river flow such that as river flows decreased during the season, so did survival estimates of barged fish (Figure 30; Appendix 2.B.4.). Although it is difficult to make definite conclusions on one year of data, it appears factors controlling survival in the 43 kilometers between the transition site (Stella) and the upper estuary (Jim Crow) are not as important as those within the 130-137 kilometers between the barge release site and Stella.

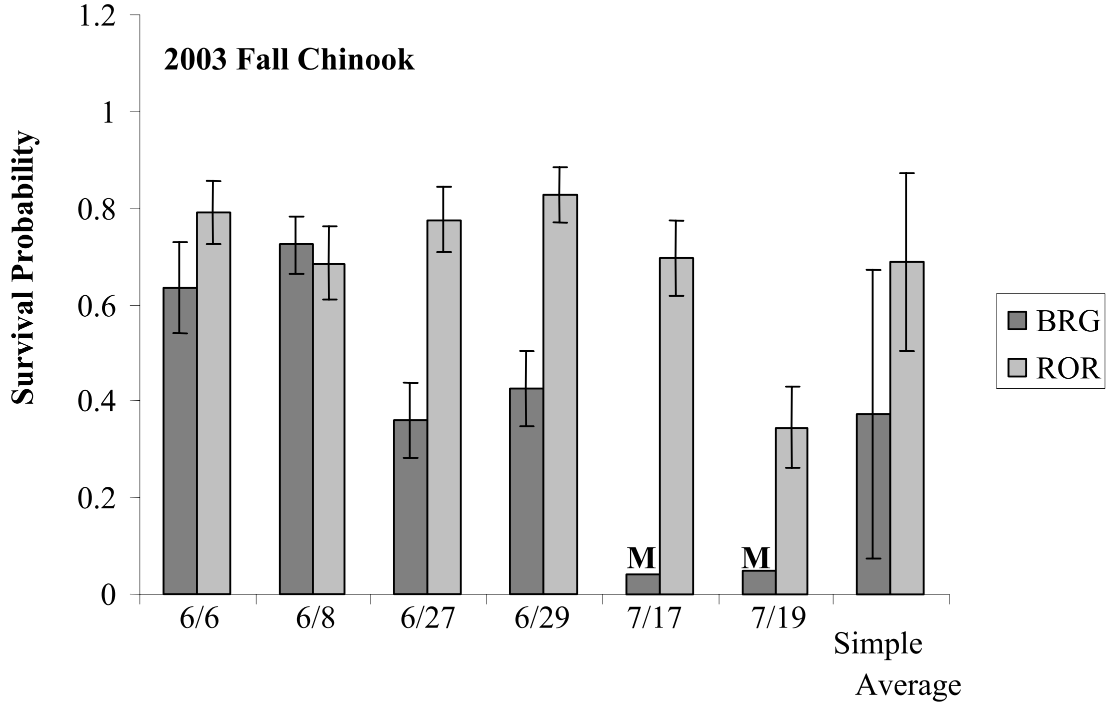


Figure 30. Survival estimates for radio-tagged barged (BRG) and run-of-the-river (ROR) juvenile fall Chinook from the release location near Bonneville Dam to Jim Crow Point (rkm 46) in the upper Columbia River Estuary for 2003. When SURPH estimates were not available (due to extremely high or low detection probabilities), simple arithmetic was used to approximate these estimates (denoted by ‘M’). Error bars on individual release days are the standard error, while those on the simple average are 95% confidence intervals.

Avian Predation

Fall Chinook were taken by avian predators to a much lesser extent than were spring/summer Chinook. Tables 19 – 21 show the percent of fish detected on the piscivorous bird colonies. Overall percentages of fall Chinook detected on the colonies ranged between 0% and 9%, which is comparable to the estimated minimum percentage of 2.3-3.5% for PIT-tagged juvenile Chinook salmon. (Ryan et al. 2003). There was no obvious and consistent trend between fish size and predation (Tables 19 – 21), suggesting that the relationship between fish size and predation rates is complex and not completely understood.

During the low flow year of 2001, mortality estimates of radio-tagged barged fall Chinook increased steadily throughout the season, whereas ROR fish remained steady at 0% (Table 19). This corroborates our results on survival estimates, which suggested that barging fall Chinook during warm periods (either late in the outmigration season or during a low flow year) leads to reduced survival. In contrast, mortality estimates for the higher flow years of 2002 and 2003 were not suggestive of a difference between barged and ROR fall Chinook; nor was there any evidence of a difference in mortality between release periods or days (Appendix 2.C.5 to 2.C.7).

Table 19. Percentages of all radio-tagged fall Chinook released and subsequently detected on the bird colonies on Rice Island in the middle estuary and East Sand Island (ESI) in the lower estuary for BRG and ROR fish in 2001. Tags were detected by plane transects and boat tracking. Average fork lengths (and ranges) are for Rice Island mortalities, East Sand Island mortalities, and overall mortalities (Rice + East Sand Islands).

2001 BRG							
Release	**Number Released**	**% Rice**	**FL for Rice**	**% ESI**	**FL for ESI**	**% of Total**	**FL**
6/13	10	0	---	0	---	**0**	---
6/23	23	4	132	0	---	**4**	132
7/5	24	0	---	8	128 (125-130)	**8**	128 (125-130)
Overall	**57**	**2**	132	**4**	128 (125-130)	**5**	129 (125-132)

2001 ROR							
Release	**Number Released**	**% Rice**	**FL for Rice**	**% ESI**	**FL for ESI**	**% of Total**	**FL**
6/13	21	0	---	0	---	**0**	---
6/23	20	0	---	0	---	**0**	---
7/5	32	0	---	0	---	**0**	---
Overall	**73**	**0**	---	**0**	---	**0**	---

The lower predation by birds on fall Chinook (as compared to spring/summer Chinook) may be a reflection of reduced numbers of fish being available to avian predators in the lower estuary, a result of in-river survival or extended upriver rearing. However, migratory behavior and migration timing may allow fall Chinook to evade predation by piscivorous waterbirds that colonize the Columbia River estuary primarily during the spring.

Table 20. Percentages of all radio-tagged fall Chinook released and subsequently detected on the bird colonies on East Sand Island (ESI) in the lower estuary for BRG and ROR fish in 2002. Tags were detected by either boat tracking or one of two fixed radio stations located on the east and west sides of the island. Average fork lengths (and ranges) are for East Sand Island mortalities.

2002 BRG Release	**Number Released**	**%ESI**	**FL**
6/14	32	**9**	138 (126-161)
6/30	31	**3**	103
7/17	41	**0**	---
Overall	**104**	**4**	129 (103-161)

2002 ROR Release	**Number Released**	**%ESI**	**FL**
6/14	40	**8**	112 (106-115)
6/30	40	**0**	---
7/17	43	**7**	115
Overall	**123**	**5**	113 (106-115)

Table 21. Percentages of all radio-tagged fall Chinook released and subsequently detected on the bird colonies on Rice Island in the middle estuary and East Sand Island (ESI) in the lower estuary for BRG and ROR fish in 2003. Tags were detected by either boat tracking or one of two fixed radio stations located on the east and west sides of the island. Average fork lengths (and ranges) are for East Sand Island mortalities.

2003 BRG Release	**Number Released**	**% ESI**	**FL**
6/6	31	**0**	---
6/8	59	**0**	---
6/27	39	**3**	124
6/29	43	**9**	115 (102-125)
7/17	46	**0**	---
7/19	41	**0**	---
Overall	**259**	**2**	117 (102-125)

2003 ROR Release	**Number Released**	**% ESI**	**FL**
6/6	44	**7**	98 (95-100)
6/8	42	**2**	105
6/27	39	**3**	107
6/29	46	**9**	107 (104-112)
7/17	38	**5**	111 (103-118)
7/19	50	**2**	111
Overall	**259**	**5**	105 (95-118)

Effects of Behavior on Survival

There is no information from our past studies on the effects of behavior on survival of fall Chinook. The majority of this information for steelhead and spring/summer Chinook came from the acoustic portion of our study. The size of acoustic transmitters available to us at the time of these studies prevented tagging of the smaller fall Chinook below a fork length of approximately 145 mm; however, we hope to re-examine this in the future with smaller tags which have been developed by Vemco, Ltd, amongst others.

Fish Size

There were differences in fish size between the BRG and ROR fish within years. During 2000-2003, BRG fall Chinook were often longer and relatively heavier than their ROR counterparts (Schreck et al. 2000, 2001*a*, 2002*a*, and 2003*b*; Jepsen et al., *in preparation*).

Fish Condition

The following gives a brief description of physiological findings of past years' studies. More specific details on the collection of fish, procedures, experimental design, and statistical analysis can be found in the Schreck et al. reports for the corresponding year.

2000

* ROR fish had significantly higher levels of ATPase than BRG fish.
* Plasma cortisol levels of BRG and ROR fall Chinook were not significantly different.
* Prevalence of bacterial kidney disease (BKD) was low, with at least 88% of the fish tested having no or low detectable levels of infection. There was no significant difference between *Renibacterium salmoninarum* (the causative agent of BKD) infection and BRG or ROR fish type.
* The percent of fish selecting saltwater was not significantly different between BRG and ROR fish in saltwater preference tests.

2001

* Occurrence of BKD was high among fish sampled at the same time as fish collected by us for tagging, with 85% of fish having detectable levels of infection. The large increase in the proportion of fish with BKD from the previous year may have been caused in part by the low-river flows experienced in 2001.
* Saltwater preference experiments indicated that ROR fish were more likely to use the saltwater portion of the tank than BRG fish. However, both groups preferred the freshwater portion of the tanks to the saltwater portion of the tanks.
* The feed intake experiment indicated that feed intake (% of body weight per feeding) did not differ between BRG and ROR fish. Both types of fish fed well once exposed to saltwater. Both groups also appeared to osmoregulate well based on muscle moisture levels, with increased water content of over 25% after 14 days. There was

no significant difference in muscle water content between the 2 groups over the course of the experiment, but on the first two dates ROR fish had greater muscle moisture than BRG fish.

*A portion of the BRG fish in one group of the feed intake experiment died, and post-mortem examination revealed that these fish were infected with a flavobacteria of marine origin (they were not tested for BKD). This research facility utilized standardized sanitation protocols and no other fish in the facility were infected with this pathogen. Therefore, we deduce that BRG fall Chinook were either carriers of this flavobacteria or were more susceptible to the disease it causes because of poorer fish condition. If other BRG fish had sublethal infection levels, then it is possible that the pathogen could contribute to delayed mortality once the fish entered saltwater. Presently it is not known why BRG fish were more susceptible to this pathogen than ROR fish.

2002

* The results of food intake experiments suggest that BRG and ROR fall Chinook were similar in their ability to osmoregulate and ingest food in a saltwater environment.
* Fish performance tests indicated that tagging appeared to have no long-term effect on energy allocation for either fish type, suggesting that tagging had no apparent adverse effects on the energy budget during migration relative to fish that experience barging or collection. Behavioral differences were not assessed.
* Observations from saltwater preference experiments showed that neither BRG nor ROR fish avoided saltwater. Replication of these experiments during a later part of the fall Chinook out-migration showed no large differences in condition or behavior. Causes for the year to year differences in the results of this test are unknown but may be due to smoltification, BKD, or stress levels in fish at the time of sampling (Seals-Price and Schreck 2003*a* and 2003*b*).
* The presence of a flavobacteria infection in barged fall Chinook for the feed intake experiment was a new finding. If other BRG fish had sublethal infection levels, then it is possible that the pathogen could contribute to delayed mortality once the fish entered saltwater. Presently it is not known why BRG fish were more susceptible to this

pathogen than ROR fish. BKD incidence was not examined in 2002.

2003

* The results of food intake experiments suggest that BRG and ROR fall Chinook were similar in their ability to osmoregulate and ingest food in a saltwater environment.

Overview

There were no differences between BRG and ROR fish in the numbers infected with BKD. In 2001, ROR fish had higher levels of ATPase than BRG fish, suggesting they were more smolted; however the saltwater preference experiments during that year found no differences between the two types. Lab experiments indicated that ROR fish were more likely to choose saltwater, although both types preferred freshwater in 2000; there was no difference in 2001 and 2002. Three years of food intake experiments found no consistent differences between BRG and ROR fish in their ability to ingest food and osmoregulate in a saltwater environment. The presence of a flavobacteria infection in BRG fall Chinook was a new finding, and suggests that ROR and BRG fish may have different resistances to this marine pathogen.

Fall Chinook migrating to LGR during July-August, in which water temperatures can exceed 70^{o} F, are often of poor quality. This poor quality could conceivably be reflected in river and estuary migration success (Figures 28-30) and subsequent marine survival.

STEELHEAD

Migratory Rates and Patterns

In-river migratory rate

ROR and BRG steelhead had similar migration speeds to rkm 89 (Stella, WA) (Figure 31). Variation in migration rates of ROR fish were more easily explained by river flow. However, migration rates within paired releases (ROR, BRG treatments) had no obvious effect on the survival estimates to the upper estuary (rkm 89) (Jepsen et al., *in preparation*).

The large variations in migration times from the current barge release site to the estuary means that steelhead do not reach the estuary as one distinct group of fish (Schreck et al. 2002*a* and 2003*a*).

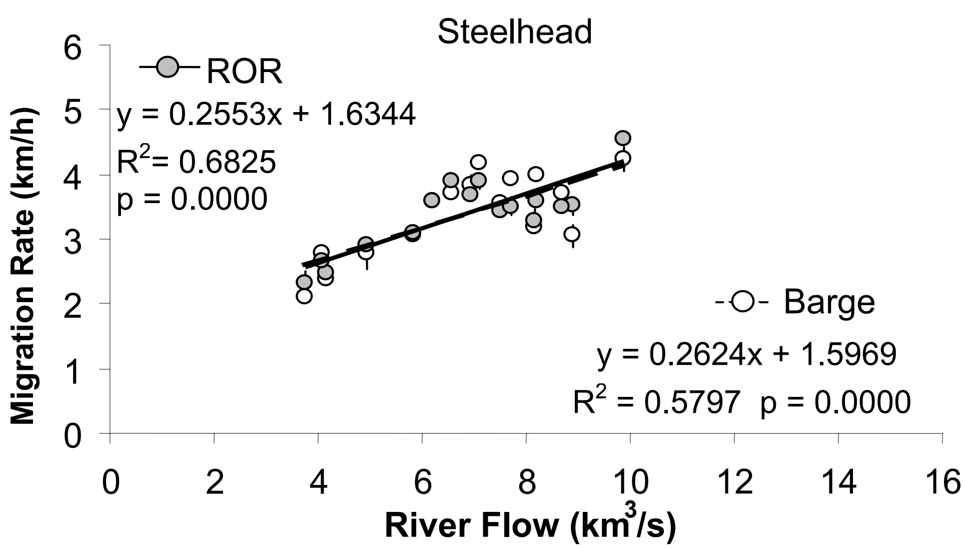


Figure 31. Average river flow from Bonneville Dam (24 hours post-release) regressed against the average migration rate for individual releases of steelhead during 2000-2003, from the release site below Bonneville Dam to the fixed radio receiver site near Stella, WA (rkm 89).

Estuarine migratory patterns and rates

Upper estuary (acoustic):

Of all acoustic-tagged fish detected at the Jim Crow Array in 2003, 95% of both BRG and ROR fish used the main shipping channel during out-migration; 5% of both types of fish used a smaller channel on the southern side of the river at this receiver array (Figure 32). Downstream of the Jim Crow Array, a number of islands form a mosaic of channels. Additional acoustic receivers were placed in key areas in the upper estuary to determine usage of smaller channels. Based on data from these receivers we identified four primary routes, shown in Figure 32. Below the Jim Crow site, the majority of the fish remained in the main shipping channel, although 20 – 30 % utilized smaller side channel habitats. There was little difference between barged and ROR fish in the use of these channels.

Steelhead used the Seal and Snag Island routes in the southern part of the estuary to a greater extent and the North Rice Island route to a lesser extent than spring/summer Chinook (Figures 11 and 32). It is not known if this was due to a “choice” of a fish to go these directions or if altered hydrodynamic variables influenced their migration path.

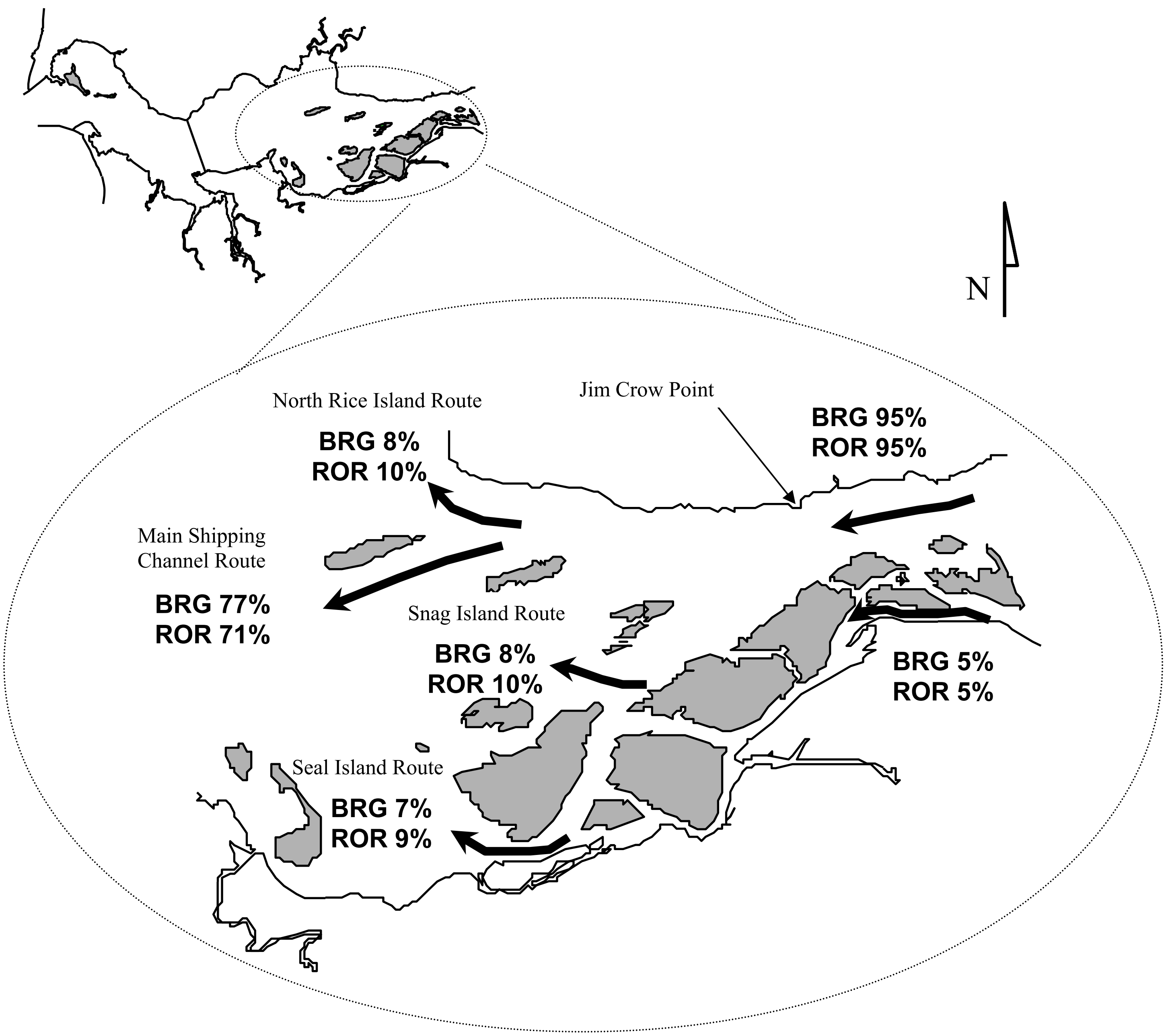


Figure 32. The percent of barged (BRG) and ROR juvenile steelhead using different migration routes in the upper Columbia River Estuary, based on acoustic receivers. All releases in 2003 were pooled.

Mid estuary (radio):

The patterns of use in the mid-estuary were studied using data from radio-tagged steelhead. Steelhead were tracked by boat in the estuary as previously described for spring/summer Chinook. In general, fish used similar routes within the mid-estuary in their migration downstream to that of spring/summer Chinook (refer back to Figures 12-14) and fall Chinook. We could detect no obvious differences between barged and ROR fish in their use of these channels. There were, however, differences in the estuarine migration rates as related to Chinook (Figure 33). In contrast to spring/summer Chinook and fall Chinook, steelhead behave less passively to the tidal cycle, generally tending to achieve a net forward gain, regardless of the tidal cycle (Figures 15, 27, and 33).

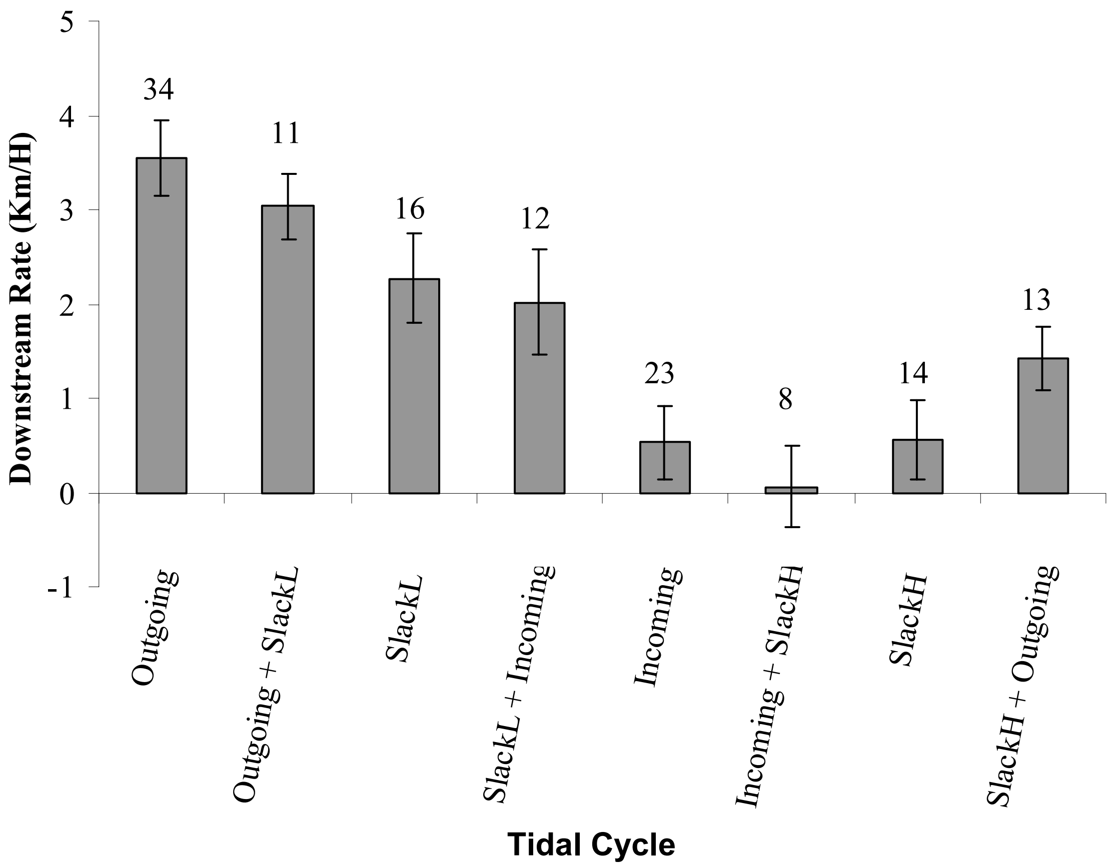


Figure 33. The weighted average downstream rate (with standard error) of juvenile steelhead for different tidal cycles, based on tracking radio-tagged fish with boats (2002-2003). The numbers above bars show the numbers of individual fish that were used to calculate the rate. The x-axis categories which have two tidal cycles listed (i.e. outgoing + slackL) were calculated from waypoints that encompassed part of both cycles. The slackL or slackH refer to a slack period in either a low or high tidal stage.

Ocean migratory patterns

The direction of steelhead migration in the near-ocean environment was examined. To compare the direction of fish migration in the near-ocean environment between BRG and ROR fish, the location (north or south side of the array) at which fish were last detected on a receiver was used. However, it is possible that fish did not exit at the last detection point, but could have moved back into the middle of the main shipping channel (where they would not be detected), and exited from there. The pooled values for all releases are shown in Table 22. There is no apparent difference in the migration direction of BRG and ROR fish in any year. Most fish were last detected on the northern line of receivers. In 2003, there was also no difference between barged hatchery (23 of 33 went north) and wild fish (26 of 35 went north) in the May 24 release, when large numbers of both reached the Ocean Array. This movement pattern may be due to the hydrodynamics of the near-shore environment and does not signify that the fish continued to move northward. Very few fish crossed over from the north to the south side of the array or vice versa. Once fish exited the array they usually were not detected again.

Table 22. The possible ocean migration direction, north or south, of acoustic-tagged barged and ROR fish for pooled releases. The migration direction was determined by the last detection location.

Year	Barged		ROR	
	% North	% South	% North	% South
2001*	64%	36%	67%	33%
2002	60%	40%	72%	28%
2003	74%	26%	77%	23%

* Includes only the first of two releases as none of the barged fish were detected on the ocean on the second release

Migratory Success

Migratory Success: In-river to Stella

Barged Fish Origin

For 2002, there was no difference in survival between radio-tagged hatchery and wild steelhead (collected at Lower Granite Dam) migrating from BON to Stella (rkm 89) (Appendix 2.B.5.). In light of these findings, data for hatchery and wild steelhead from Lower Granite Dam were pooled for comparisons of survival estimates between barged fish from Lower Granite and McNary Dams.

There was no difference in survival between radio-tagged steelhead from Lower Granite Dam and radio-tagged hatchery steelhead from McNary Dam (Appendix 2.B.6.). Therefore, data for Lower Granite steelhead and McNary steelhead were pooled for comparisons of survival estimates between barged and ROR fish.

For 2003, the results of the logistic regression are suggestive of an interaction effect of release day and origin of fish from Lower Granite Dam, where survival may affect hatchery steelhead differently than wild steelhead on different days of the season (Appendix 2.B.8.). However, 'origin' was not significant, suggesting that there were no overall differences in survival between hatchery and wild steelhead. Therefore, these data were collectively pooled for comparisons between barged and ROR steelhead survival estimates to Stella.

Our data suggest no differences in survival between radio-tagged barged hatchery and wild steelhead, or between steelhead collected at Lower Granite Dam versus McNary Dam.

BRG versus ROR

In 2002, radio-tagged ROR steelhead exhibited consistently and significantly higher survival estimates than barged fish to Stella (Figure 34; Appendix 2.B.7.). The logistic regression model also indicated that flow had a significant, positive effect on survival (Appendix 2.B.7.).

In 2003, results of the logistic regression model were suggestive of a higher survival of barged steelhead than ROR fish to Stella during the middle and late periods (Figure 35; Appendix 2.B.9.).

Our data suggest that barging steelhead during the middle-late dates of the outmigration may be more conducive to survival than leaving the fish in-river. It is also apparent that there is variation in survival between days and weeks within a year, as well as between years.

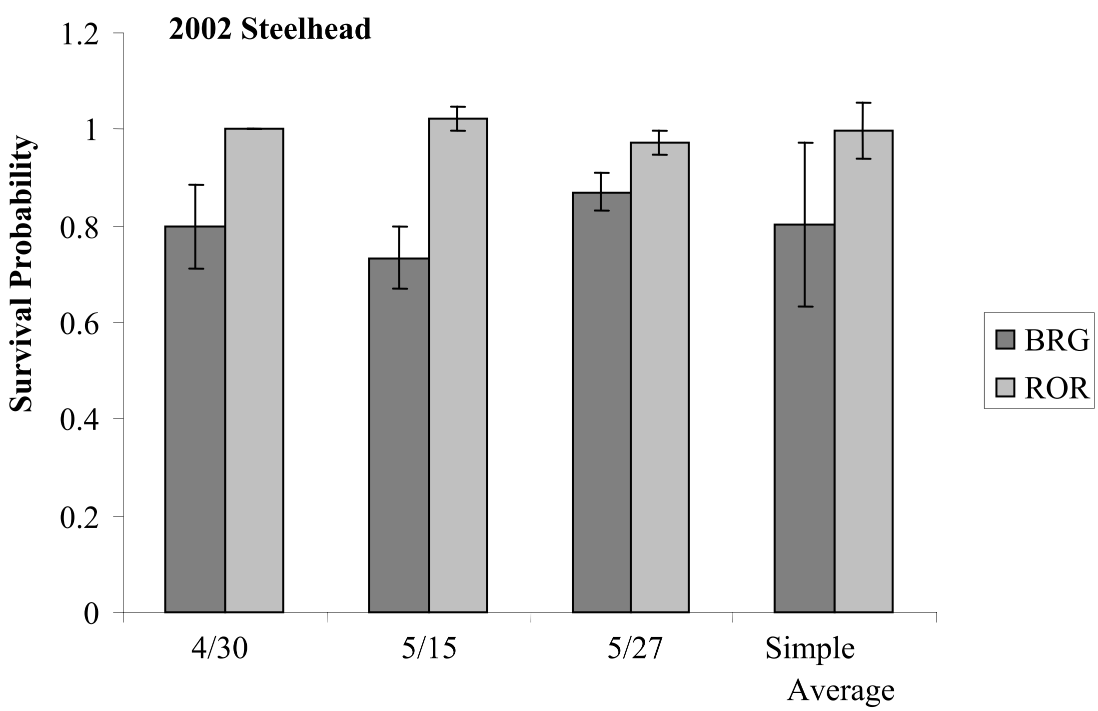


Figure 34. Survival estimates for radio-tagged barged (BRG) and run-of-the-river (ROR) juvenile steelhead from the release location near Bonneville Dam to Stella, WA (rkm 89), in the lower Columbia River. Error bars on individual release days are the standard error, while those on the simple average are 95% confidence intervals. All ROR fish survived on the 4/30 release.

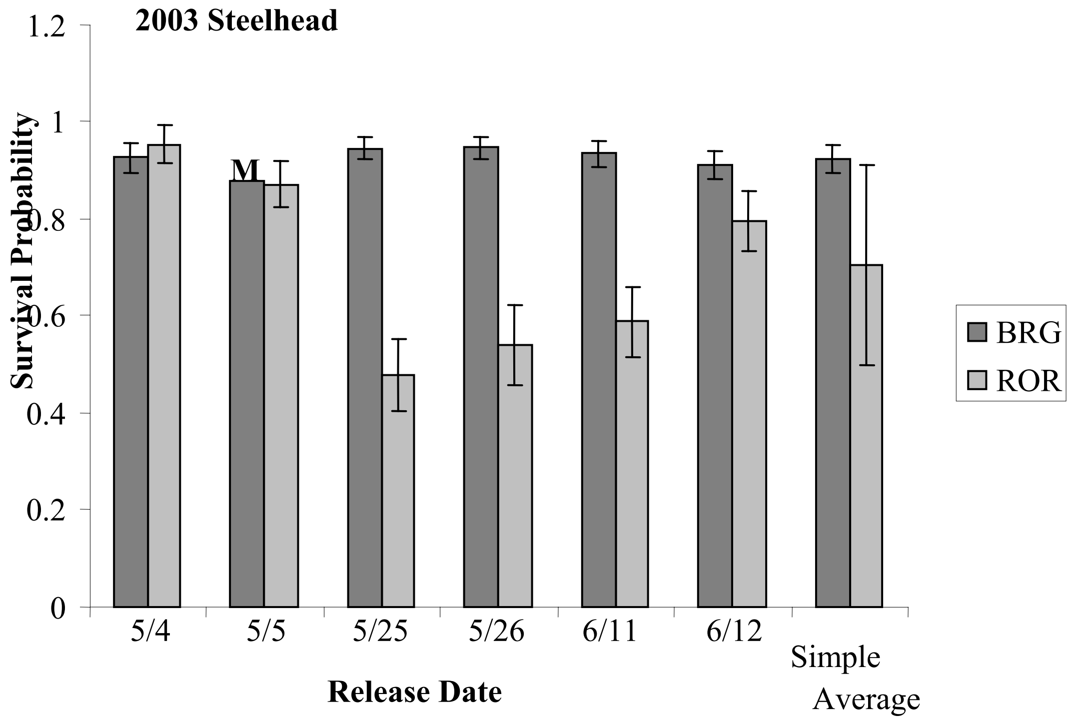


Figure 35. Survival estimates for radio-tagged barged (BRG) and run-of-the-river (ROR) juvenile steelhead from the release location near Bonneville Dam to Stella, WA (RKM 89), in the lower Columbia River. A SURPH estimate was not available for BRG fish on 5/5 (due to a low detection probability of approximately 0%), simple arithmetic was used to approximate these estimates (denoted by 'M'). Error bars on individual release days are the standard error, while those on the simple average are 95% confidence intervals.

Migratory Success: In-river to Jim Crow

Barged Fish

In 2003, there were no differences in survival estimates of radio-tagged barged hatchery and wild steelhead migrating from BON to Jim Crow point. However, there was a significant effect of the interaction between day and origin, suggesting that the release day affected survival of hatchery steelhead different from wild, although this was not consistent because 'origin' was not significant (Appendix 2.B.10.). Based on these results, data for hatchery and wild steelhead were collectively pooled for comparisons between barged and ROR fish.

BRG versus ROR

In 2002 there were no differences in survival estimates of barged and ROR steelhead from BON to Jim Crow point (Figures 36). In 2003, although ROR fish appeared to survive in lower proportions than barged fish during the middle and late portions of the run, these trends were not significant (Figure 37). Release day, however, did have a significant effect on survival (Appendix 2.B.11.).

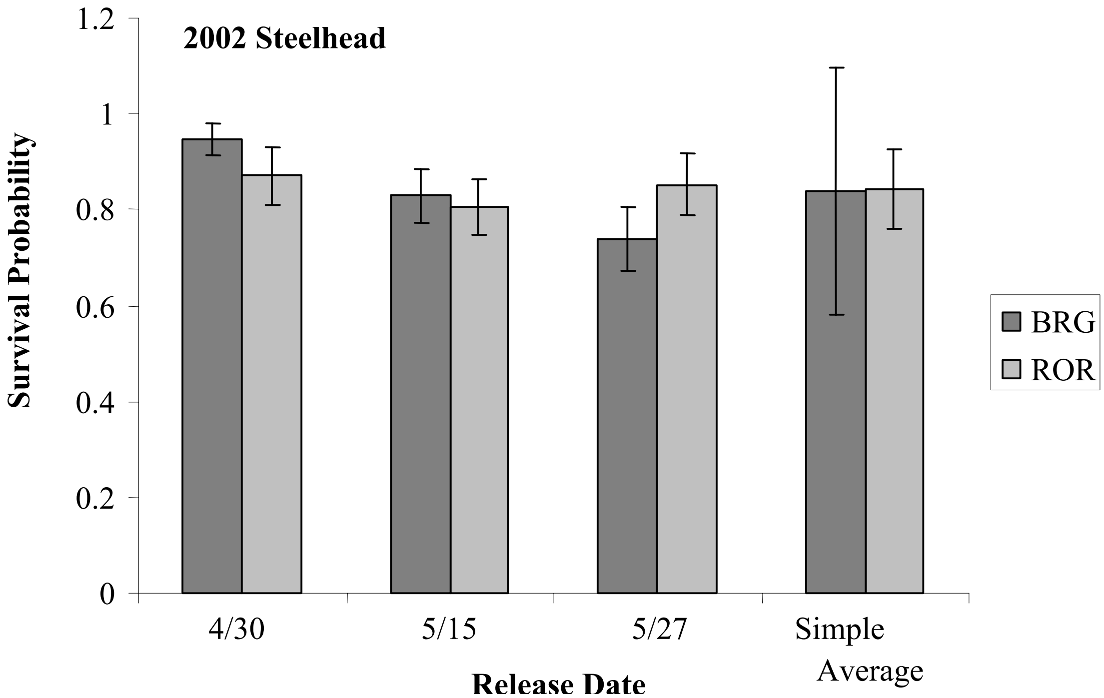


Figure 36. Survival estimates for acoustic-tagged barged (BRG) and run-of-the-river (ROR) juvenile steelhead from the release location near Bonneville Dam to Jim Crow Point (rkm 46) in the upper Columbia River Estuary. Error bars on individual release days are the standard error, while those on the simple average are 95% confidence intervals.

With the exception of the first release date, survival estimates of radio-tag steelhead to Jim Crow were comparable with those of acoustically-tagged fish (Figure 37). Steelhead are known to be "hardy" fish, and our acoustic tags were within 3.4% of the body weight of the fish, well within acceptable limits (Brown et al. 1999; Jepsen et al., *in press*).

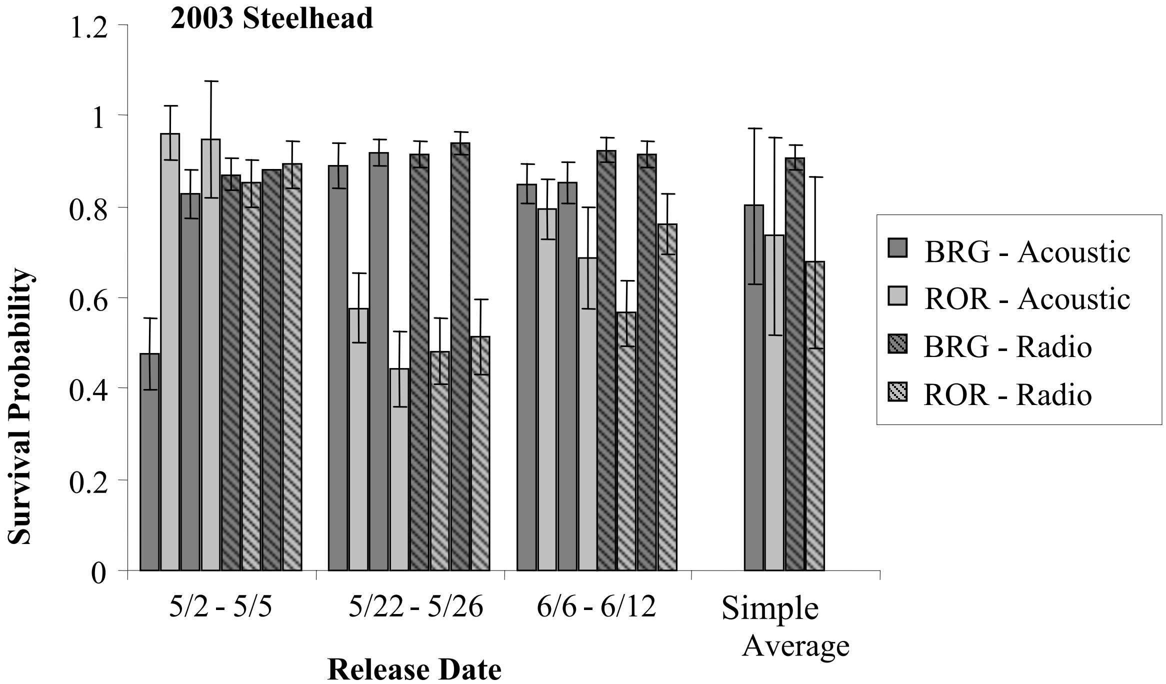


Figure 37. Survival estimates for acoustic and radio-tagged barged (BRG) and run-of-the-river (ROR) juvenile steelhead from the release location near Bonneville Dam to Jim Crow Point (RKM 46) in the upper Columbia River Estuary for 2003. Error bars on individual release days are the standard error, while those on the simple average are 95% confidence intervals.

Avian Predation

Steelhead were taken by avian predators to a greater degree than spring/summer or fall Chinook (Tables 23 – 25). This agrees with the general trend for PIT tag studies (Ryan et al. 2003). Overall 0-40% of all radio-tagged juvenile steelhead were detected on the piscivorous bird colonies, which is up to twice the minimum estimate reported by Ryan et al. (2003), who reported an estimated minimum percentage of 10.0-14.2% for juvenile steelhead salmon. The reason for this difference is unclear. As with our spring/summer Chinook data, this may be attributed to varying detection efficiencies (45-95%) of PIT tags on the piscivorous bird colonies (Glabek et al. 2003), selective predation pressure on the radio-tagged fish, or radio tags observed in locations not surveyed for PIT tags (i.e., rugged terrain and water around the periphery of the island). There was no trend between fish size and predation (Tables 23 – 25), suggesting that the relationship between fish size and predation rates is complex and not completely understood.

In 2001, there were no significant differences in mortality estimates between barged hatchery and barged wild steelhead (Appendix 2.C.9.). Therefore, these data were pooled. There were no significant differences in mortality estimates between barged and ROR fish. However, there was a significant effect of release day on mortality (Appendix 2.C.9.). We want to emphasize this point, that release day is a very important variable affecting mortality, as we have also found with spring/summer Chinook and fall Chinook.

In 2002, there was no evidence that mortality estimates were different between barged hatchery and barged wild steelhead (Appendix 2.C.10.). Therefore, these data were pooled for comparisons with barged hatchery steelhead collected at McNary Dam. The data were suggestive of a relatively higher mortality estimate of barged steelhead collected from Lower Granite Dam in relation to barged steelhead collected from McNary Dam (Appendix 2.C.11.). Mortality estimates for ROR steelhead were intermediate to those of Lower Granite (highest) and McNary (lowest). There was no evidence for a difference in mortality between ROR steelhead and barged fish collected from Lower Granite or between ROR steelhead and barged fish collected from McNary Dam (Appendix 2.C.12.).

In 2003, mortality estimates for barged hatchery and barged wild steelhead were compared during the middle and late release dates. There was no evidence for a difference in mortality estimates between barged hatchery and barged wild steelhead (Appendix 2.C.13.); therefore, barged hatchery and barged wild steelhead were pooled for comparisons with ROR fish. There was no evidence for a difference in mortality between barged and ROR passage types (Appendix 2.C.14.).

Table 23. Percentages of all radio-tagged steelhead released and subsequently detected on the bird colonies on Rice Island in the middle estuary and East Sand Island (ESI) in the lower estuary for BRG and ROR fish in 2001. Tags were detected by plane and boat transects. Average fork lengths (and ranges) are for Rice Island mortalities, East Sand Island mortalities, and overall mortalities (Rice + East Sand Islands).

2001 BRG

Release		Number Released	% Rice	FL for Rice	% ESI	FL for ESI	% of Total	FL
4/30*		**28**	**7**	254 (248-260)	**4**	222	**11**	243 (222-260)
	H	18	11	254 (248-260)	6	222	**17**	243 (222-260)
	W	10	0	---	0	---	**0**	---
5/8*		**30**	**0**	---	3	208 (205-210)	**7**	208 (205-210)
	H	15	0	---	7	210	**7**	210
	W	15	0	---	7	205	**7**	205
5/21*		**30**	0	---	3	208	**3**	208
	H	15	0	---	7	208	**7**	208
	W	15	0	---	0	---	**0**	---
5/30*		**36**	0	---	3	230	**3**	230
	H	22	0	---	0	---	**0**	---
	W	14	0	---	7	230	**7**	230
Overall		**124**	**2**	254 (248-260)	**4**	215 (205-230)	**6**	226 (205-260)

2001 ROR

Release	Number Released	% Rice	FL for Rice	% ESI	FL for ESI	% of Total	FL
4/30	15	0	---	7	220	**7**	220
5/8	15	0	---	0	---	**0**	---
5/21	15	0	---	0	---	**0**	---
5/30	24	0	---	0	---	**0**	---
Overall	**69**	**0**	**---**	**1**	220	**1**	220

Table 24. Percentages of all radio-tagged steelhead released and subsequently detected on the bird colonies on East Sand Island (ESI) in the lower estuary for BRG and ROR fish in 2002. BRG fish consisted of Lower Granite Hatchery (LGR H), Lower Granite Wild (LGR W), and McNary Hatchery (MCN H). Tags were detected by either boat transects or one of two fixed radio stations located on the east and west sides of the island. *Pooled counts for barged steelhead. Average fork lengths (and ranges) are for East Sand Island mortalities.

2002 BRG			
Release	**Number Released**	**% ESI**	**FL**
5/4*	**46**	**15**	201 (178-225)
LGR H	16	31	195 (178-212)
LGR W	15	7	225
MCN H	15	7	210
5/20*	**51**	**27**	205 (162-229)
LGR H	22	27	212 (185-228)
LGR W	14	43	194 (162-229)
MCN H	15	13	215 (207-222)
6/1*	**99**	**22**	
LGR H	34	26	217 (201-242)
LGR W	31	19	221 (192-245)
MCN H	34	21	235 (204-285)
Overall	**392**	**11**	214 (162-285)

2002 ROR			
Release	**Number Released**	**% ESI**	
5/4	16	**13**	208 (202-214)
5/20	14	**21**	249 (224-276)
6/1	39	**18**	230 (195-287)
Overall	**69**	**17**	231 (195-287)

Table 25. Percentages of all radio-tagged steelhead released and subsequently detected on the bird colonies on East Sand Island (ESI) in the lower estuary for BRG and ROR fish in 2003. BRG fish consisted of Lower Granite Hatchery (LGR H), and Lower Granite Wild (LGR W). Tags were detected by either boat transects or one of two fixed radio stations located on the east and west sides of the island. †Pooled hatchery and wild fish. Average fork lengths (and ranges) are for East Sand Island mortalities.

2003 BRG Release	Number Released	% ESI	FL
5/4	**91**	**27**	210 (189-239)
5/5	**90**	**38**	222 (194-268)
5/25†	**91**	**26**	200 (145-246)
LGR H	47	26	224 (174-246)
LGR W	44	27	176 (145-200)
5/26†	**94**	**15**	217 (168-254)
LGR H	47	19	236 (217-254)
LGR W	47	11	182 (168-199)
6/11†	**92**	**40**	211 (163-262)
LGR H	59	42	217 (165-262)
LGR W	33	36	198 (163-246)
6/12†	**92**	**32**	199 (140-294)
LGR H	63	30	211 (181-294)
LGR W	29	34	175 (140-207)
Overall	**550**	**30**	210 (140-294)

2003 ROR Release	Number Released	% ESI	FL
5/4	47	**17**	210 (182-240)
5/5	47	**28**	222 (179-246)
5/25	46	**9**	222 (206-230)
5/26	37	**16**	342 (210-245)
6/11	46	**28**	249 (188-280)
6/12	45	**33**	239 (195-272)
Overall	**268**	**22**	231 (179-280)

Effects of Behavior on Survival

As mentioned previously, there were several migration patterns in the upper estuary. In 2003, median time from the Jim Crow Array to the Astoria Bridge Array for steelhead using the main shipping channel was 11.6 h, while the median for those using the Snag Island route was 15.1 h (Schreck et al. 2003*a*). This time difference may have affected survival in the estuary. Fish using the Snag Island route 3.5 h longer to migrate than those using the main shipping channel, possibly increasing vulnerability to predators through exposure time. However, this would depend on the numbers of predators in a specific area. Due to the small numbers of fish using these backwater routes, it is difficult to make conclusions on the effects of these routes on vulnerability to predators.

A more comparable route effect was derived from the acoustic data collected at the Astoria Bridge Array. In general, fish used one of three main routes when passing under the Astoria Bridge: 1) passing this area in the main shipping channel (OR), 2) through a complex of smaller channels in the center of the river, or 3) the northern channel (WA). It appeared that barged and ROR fish use these channels in slightly different proportions within and between years; proportions for each release is given in Appendix 4, Tables 10 - 11 (2002-2003). If the acoustic releases for 2002 are pooled, use of these channels was as follows: 46% of BRG fish and 36% of ROR fish used the Oregon channel; 20% of BRG fish and 20% of ROR fish used the middle channel and 34% of BRG fish and 44% of ROR fish used the Washington channel. If the acoustic releases are pooled for 2003, 31% of BRG fish and 38% of ROR fish used the Washington channel, 19% of BRG fish and 28% of ROR fish used the middle channel, and 50% of BRG fish and 34% of ROR fish used the Oregon channel. The subsequent detections of these fish on the Ocean Array may represent an index of their relative survival when using these routes. In both years, our data suggests that steelhead using the Washington channel had the lowest survival in the area between the Astoria Bridge and the ocean environment (Appendix 4, Tables 1 and 2). This may be due to the Washington channel's close proximity to the avian predators on East Sand Island.

Fish Size

There were differences in fish size between the BRG and ROR fish within years. However, as explained previously, we will not elaborate on these differences as we have not discovered the link between general fish condition and consequent survival. In general, during 2000-2003, the ROR steelhead were often longer than their BRG counterparts, whereas BRG steelhead were heavier at a given fork length (Schreck et al. 2000, 2001*a*, 2001*b*, 2002*a*, 2002*b*, and 2003*a*; Jepsen et al., *in preparation*).

Fish Condition

Barged Fish Origin

The only physiological tests between BRG hatchery and BRG wild occurred in 1996. More specific details on each the collection of fish, procedures, experimental design, and statistical analysis can be found in the Congleton et al. (1996).

* Gill Na^+, K^+-ATPase levels were relatively low in hatchery and wild steelhead smolts sampled from barges at Lower Granite Dam in early May and increased significantly by mid-May. Advancing smoltification of hatchery fish was also suggested by a progressive decline in condition factor over time. These data imply that steelhead smolts transported and released below BON in late April and early May are not as physiologically prepared to move into full-strength seawater as are smolts transported several weeks later.
* Plasma cortisol and glucose concentrations were relatively high and plasma Na^+ and Cl^- concentrations relatively low in both hatchery and wild steelhead sampled at Lower Granite Dam in mid- to late May, potentially indicating seasonal maximum stress responses. Stress responses were not correlated with steelhead loading densities.
* Plasma cortisol and glucose concentrations were significantly higher in hatchery than in wild steelhead. Plasma Na^+ and Cl^- concentrations were similar in hatchery and wild fish: in this critical area of performance, hatchery and wild fish performed equally well. Wild fish apparently gained body water after collection and barge loading at Lower Granite Dam on dates when stress responses were strongest. The more advanced stage of smoltification of wild fish may make them more susceptible to stress- and exercise-induced disturbances of water balance than hatchery fish.
* Cortisol concentrations declined steeply in both hatchery and wild fish during barge transportation on all sampling dates, indicating that conditions in the fish

transportation barges were not stressful for steelhead. This observation differs from results obtained with Chinook salmon in 1994 and 1995, when cortisol concentrations remained high in transported fish on some occasions.

* Plasma cholesterol and triglyceride concentrations were significantly higher in hatchery fish than wild, indicating differences in lipid metabolism. Cholesterol and total protein concentrations declined significantly during barge transportation of both hatchery and wild fish; it is presently unclear whether these changes were due to recovery following exposure to collection and loading stressors, or to cessation of feeding during barge transportation. A significant decline in triglyceride concentrations for wild fish but not for hatchery fish during transportation is attributed to cessation of feeding and larger lipid reserves in the hatchery fish.

Overview

Barging of both hatchery and wild steelhead early in the season may not be as beneficial as fish may not be physiologically ready (ATPase levels) to move into full strength seawater. Both hatchery and wild steelhead had decreased levels of cortisol during transport, indicating that barging was not severely stressful on steelhead. The level of cortisol was not correlated with loading densities.

General physiology (BRG versus ROR)

The following gives a brief description of physiological findings of past year's studies. More specific details on each the collection of fish, procedures, experimental design, and statistical analysis can be found in the Schreck et al. reports for the corresponding year.

2000

* ROR fish had significantly higher levels of Gill Na^+/K^+ ATPase than BRG fish on the first release, but not on the second and third releases. There was no significant difference in ATPase levels between releases for ROR fish, although there was for BRG fish.
* ROR fish had significantly higher plasma cortisol levels than BRG fish on two of the

three releases. This could suggest either higher stress levels for in-river migrants or a difference in holding or collection techniques between fish types. There was a strong relationship between mean cortisol levels and number of smolts arriving at BON (smolt counts) for ROR fish.

* Prevalence of bacterial kidney disease (BKD) was low throughout the season, with 100% of the fish having no or low detectable levels of infection. There were no differences in BKD levels between fish types within a release or between releases within a type.
* Saltwater preference experiments indicated no significant difference between BRG and ROR fish in the percent of fish selecting saltwater at 60 minutes or 120 minutes after the start of the experiment.
* The feed intake experiment indicated that feed intake (% of body weight per feeding) did not differ significantly between BRG and ROR fish on any given day. Both types of fish fed well once exposed to saltwater. Fish in both groups appeared to osmoregulate well based on plasma sodium, plasma potassium, and muscle moisture levels. Only one mortality in both types of fish occurred during the experiment, suggesting no differences in mortality after 14 days in saltwater.

2001

* Occurrence of BKD was high among fish collected at the same time as tagged fish, with 62.5% of fish (N = 40) having detectable levels of infection. There was no statistical difference between BRG and ROR fish, although the infection levels were quite variable within the date.

2002

* From food consumption experiments, BRG and ROR steelhead had similar physiological condition, osmoregulation, and relative abilities to ingest food in a saltwater environment.
* From fish performance experiments, tagging had no short-term (5 day) effect on energy allocation for either fish type, indicating that the implantation of transmitters did not adversely influence energy function in these fish.

* Observations from saltwater preference experiments showed that neither BRG nor ROR fish avoided saltwater. From these experiments we found no meaningful difference in these measures of condition and behavior between early and late collection dates.

2003

* During the first two weeks of saltwater entry both BRG and ROR steelhead had similar physiological condition, osmoregulatory ability, and appetite.

Overview

Differences in early season ATPase levels between BRG and ROR fish suggests that barging fish early in the season may not be as beneficial as mid to late season strategies. However, conclusions based on ATPase levels should be considered tenuous. BKD varied from low detections in both fish types in 2000, to high levels in 2001; no differences existed between BRG and ROR fish. Diseased fish would have a low probability of surviving in saltwater. We also found no differences between BRG and ROR fish in their preference for saltwater, food intake after introduction to saltwater, and osmoregulatory abilities.

MANAGEMENT RECOMMENDATATIONS

Alternate Barge Release Strategies

We hypothesize that the current barge release strategies may be improved with some modifications. These modifications are species and strain-specific and could be studied in depth if additional transportation barges are in place.

Early data (Schreck et al. 1994 and 1995; Schreck and Stahl 1998) suggested that stress levels in spring/summer Chinook increased as the fish transitioned through the collection system and into the transportation barges, but decreased significantly during transit in the early portion of the run. The inability of these fish to recover in the barge during the middle and late periods of the outmigration season is likely a reflection of high loading densities in the barge and increased smoltification levels, which compromise the ability of the fish to handle stress and loading with steelhead during the end of the run (Schreck et al. 1995; Kelsey et al. 2002). Lowering barge densities and reducing co-transportation with steelhead may be technically simple ways to reduce stress and possibly reduce delayed mortality for spring/summer Chinook.

Stress data on BRG and ROR fall Chinook were equivocal (Schreck et al. 2000). However, fall Chinook migrating to LGR during July-August, in which water temperatures can exceed 70^{o} F, are often of poor quality. This poor quality appears to be reflected in poor survival during the latter portion of the run (Schreck et al. 2002*a* and 2002*b*). Based on these data, it appears that barging fall Chinook during the latter portion of the run is not conducive to survival.

ROR steelhead had significantly higher plasma cortisol than BRG fish, suggesting that in-river migration was more stressful than barge transportation (Schreck et al. 2000). BRG fish had decreased levels of cortisol during transport, indicating that barging was not stressful on steelhead. Cortisol levels were not correlated with loading densities. Barging steelhead early in the season may not be beneficial to survival, as these fish may not be physiologically ready to move into full strength seawater (Congleton et al. 1996; Schreck et al. 2000).

Upper estuary patterns for steelhead and spring/summer Chinook suggest that the fastest route for fish is in the main shipping channel. If mortality in the estuary is a function of residence time, mortality could be reduced by keeping the fish in the shipping channel; however more modeling needs to be done to determine if any management options are available such as river flow modifications to adjust for behavior. In-river and estuarine migration rates are correlated with river flow, so to decrease residence times, and possibly reduce mortality, river flow may be increased.

The data from 2002 and 2003 suggests that steelhead using the Washington channel have lower index of survival from the bridge to the ocean array relative to fish using other routes. This may be due to proximity of the Washington channel to the large piscivorous bird colonies on East Sand Island. There may be management options, such as alternative dredging operations or timing of barge releases, to reduce the number of fish using the Washington channel and possibly increase their survival.

Based on our data, variation in fish quality and ability to migrate and survive into the marine environment appear to be largely attributable to release date, with barging during the early part of the season appearing to be less beneficial to spring/summer Chinook and steelhead. Our previous studies focused only on year effects and were not designed to give definitive answers on early barging issues. This could be studied extensively with many releases specifically in this time period. We have also shown that survival estimates of barged fish vary within releases as well as across the run, and we believe that adaptive management of outmigrating juvenile salmon should include fish condition monitoring at Snake River Dams as a means of suggesting when fish should be barged.

Our findings suggest the most direct option to increase survival of barged fish is to have alternate barge release locations within the estuary. This would eliminate in-river mortality between the current release site and the new release sites. Also the release of fish could possibly be managed in such a way to reduce avian predation. From our data, it appears that steelhead and spring/summer Chinook would benefit most by this technique. Alternative release strategies may avoid predation levels as high as 23% for spring/summer Chinook and 29% on select release dates for steelhead, although percentages vary from year to year. For fall Chinook, barging during the latter part of the season does not appear conducive to survival, which may be a function of circulating warm water through the barge (due to river stratification; see Hoffarth 2000). We have examined and will discuss how data collected on spring/summer Chinook in 2004 relates to these management alternatives; however, these will also be applied to steelhead.

Initially, we hypothesized barge releases near Bonneville Dam could be managed with the use of modeled movements. Although, as Figure 38 shows, there is much variation in the time of arrival in the estuary for fish released as a group near Bonneville Dam; therefore, it would not be possible to predict when a barge should release fish to get them to the estuary at the most opportune tidal cycle. We suggest two sites in the Columbia River estuary for alternate barge release locations: at the Astoria Bridge on the Oregon side and at Jim Crow Point. We have examined the potential of these sites with the main objective of reducing avian predation on smolts. If our main objective were to eliminate differential delayed mortality, we would recommend improving barge hold conditions and utilizing run-specific barging in place of barging throughout the season for each fish species or strain. For example, barge hold conditions could be improved for spring/summer Chinook by minimizing cotransportation with steelhead; for steelhead and fall Chinook, run-specific barging could be achieved in such a way that steelhead are not barged during the early portions of the run (this also minimizes stress for spring/summer Chinook) and fall Chinook are not transported during the latter portions of the run.

To reduce avian predation on smolts at the Astoria Bridge site, the goal is to have the fish migrate past the avian predator colonies on East Sand Island during hours of darkness (when the birds are not actively feeding). For the releases at the Jim Crow site, fish may be managed so that the fish are not holding during incoming and slack tides near East Sand Island. Given that it would be more cost-effective to release fish further upstream than downstream, it is important to establish a relationship between benefits to survival relative to distance from the ocean. Hence, we recommend the evaluation of these two sites based on their spatial separation and the ability to monitor effectiveness. If the Corps of Engineers chooses to continue to use the contemporary release site below Bonneville, then release times should be coupled with Bonneville discharge in such a way that fish will reach the estuary at a peak of an outgoing tide. This goal is exceedingly difficult, given that fish do not migrate to the Columbia River estuary as one distinct pulse of fish and can experience any one of a number of periods in the tidal cycle (Figure 38).

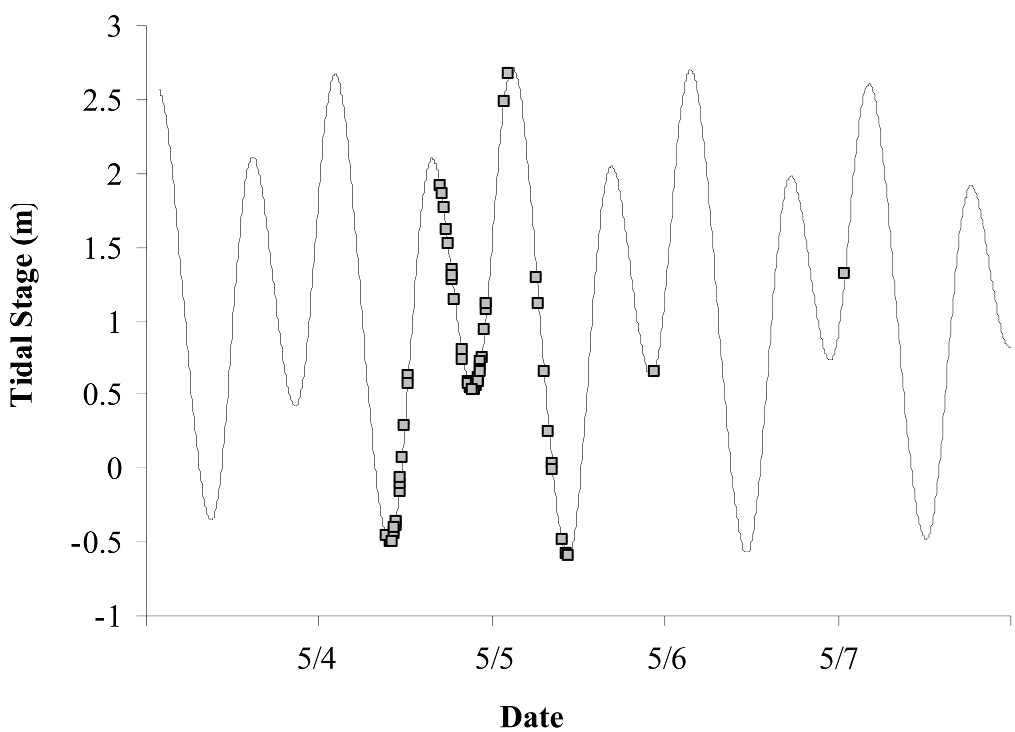


Figure 38. The tidal stage near the Jim Crow Array (rkm 46) is plotted with the date and time when individual spring/summer Chinook (boxes) were first detected at the Jim Crow Array during the first release below Bonneville Dam (contemporary release site) in 2004 for spring/summer Chinook. Two fish are not shown that arrived after May 8, 2004.

For the Astoria Bridge release site, we propose a test to release fish in the main shipping channel (Oregon side), at night during the peak of a large outgoing tide (~ 8-10’ difference between the high and low tidal stage). The acoustic-tagged spring/summer Chinook detected at the Astoria Bridge in 2004 were used to establish the proportion of fish that could migrate to the ocean within the same outgoing tide in which they were detected. We created a subset of the data with fish that were last detected within three hours of the peak of a high tide. Of those fish, 76% (97 of 128) were able to migrate to the ocean within that outgoing tide; the remainder of the fish held for an incoming tide before reaching the ocean on the next outgoing tide. The Oregon side of the bridge was chosen because modeled water particles (CORIE) released on a smaller outgoing tide (4') on both sides of the Astoria Bridge (Washington and Oregon) were not able to reach the ocean within that first outgoing tide. As a result, the particles released on the Washington side held directly around East Sand Island until the next outgoing tide. Since not all released fish will migrate to the ocean within the outgoing tide in which they were released, those fish holding on the Washington side may be more exposed to avian predation.

At the Jim Crow release site, modeled fish movements and holding patterns are necessary to predict migration behavior with relation to tides, daylight, and location in the Columbia River estuary. To model these movements, we first started a fish's movement at a point in a certain tidal stage and time of day at Jim Crow point. We then used the weighted average downstream rates (Table 26, presented previously for data collected from tracking fish with boats) for a given race/species to estimate movements and holding patterns. For example, if we simulated spring/summer Chinook fish released at the peak of a high tide at Jim Crow point (rkm 46), the fish would be simulated as such: the fish would first experience a slack high tide for 0.5 h and move downsteam at 0.4 km/h, at the end of this period the fish would be at rkm 45.8; the fish would now experience an outgoing tide for 6 h and move at the rate of 3.1 km/h, at the end of the outgoing tide the fish would be at rkm 27.2 (rkm 45.8 – distance traversed of 18.6), et cetera, until the fish reached the ocean.

Table 26. The downstream rate (km/h) and associated standard error of Chinook and steelhead as determined from tracking individual fish with boats. Rates are weighted averages (based on the number of measurements) of individual rates.

	Fall Chinook		Spring/summer Chinook		Steelhead	
Tidal Cycle	Downstream Rate (km/h)	SE	Downstream Rate (km/h)	SE	Downstream Rate (km/h)	SE
Outgoing	2.9588	0.2665	3.1450	0.2101	3.5412	0.3974
SlackL	2.5745	0.3008	1.9458	0.3305	2.2686	0.4708
Incoming	-0.1115	0.2037	-0.3317	0.1894	0.5307	0.3870
SlackH	0.1934	0.2785	0.4013	0.2632	0.5569	0.4130

To examine the differences of fish movements in relation to releasing fish on different tidal cycles, we simulated fish movements on all available tides for May 5, 2004. Figures 39 and 40 show the patterns of movement in relation to "hours of darkness" for simulated spring/summer Chinook and steelhead. Releases at the low tides are not shown, as spring/summer Chinook in both simulations held for several hours (in which they may be exposed to predators) during the incoming tide before their movements showed the same patterns depicted in Figure 39 and 40. The differences between the two simulated movements is obvious; simulated fish released at 3:05 pm (shown in Figure 39), are holding near the avian predators on East Sand Island during daylight hours, while those released at 1:45 am (Figure 40) are holding (spring/summer Chinook) or moving slowly (steelhead) in this location during hours of darkness. From these simulations, if fish were to be released at Jim Crow Point on May 5, 2004, it should be done at 1:45 am. For any fish releases made at Jim Crow Point, it would be necessary to use this type of simulation to determine the "best" tide for a given day. It may be possible to produce a more accurate model, which uses tide tables for different locations in the estuary and different downstream rates based on the explanatory variables for rates at various tidal cycles (i.e. Bonneville flow, twilight, tidal strength).

To validate this model, we compared real fish that were detected at both the Jim Crow Array and the Ocean Array against simulated fish. For each individual fish detection (spring/summer Chinook, 2004), we used the point in time and the tidal cycle when fish were last detected at the Jim Crow Array, then simulated that fish's movement and holding patterns. Since the holding location of real fish was not known, we compared total migration time of individual real and simulated fish. The assumption in this comparison is that if total migration time of the two groups is similar, then their holding locations should also be similar. Table 27 shows the difference in migration times between real and simulated fish. The percentage varies between releases, for pooled releases, 32% of fish detected on both the Jim Crow and Ocean Arrays (real fish) migrated that distance within 3 h of the simulated time; 43% of real fish migrated that distance within 6 h of the simulated time. This suggests approximately half of the fish released at this location could be managed exceptionally well and the remainder of the fish should probably still fair better than those of a release just below Bonneville Dam.

The model we have presented is a relatively simple one, accounting only for tidal influences, daylight, and predicted migration rates. Differences between model predictions and reality can be attributed in part to the unknown patterns of individual fish behavior. For example, differences between migration timing for simulated fish and real fish may be the result of real fish foraging and thus displaying different holding times or migration rates than simulated fish.

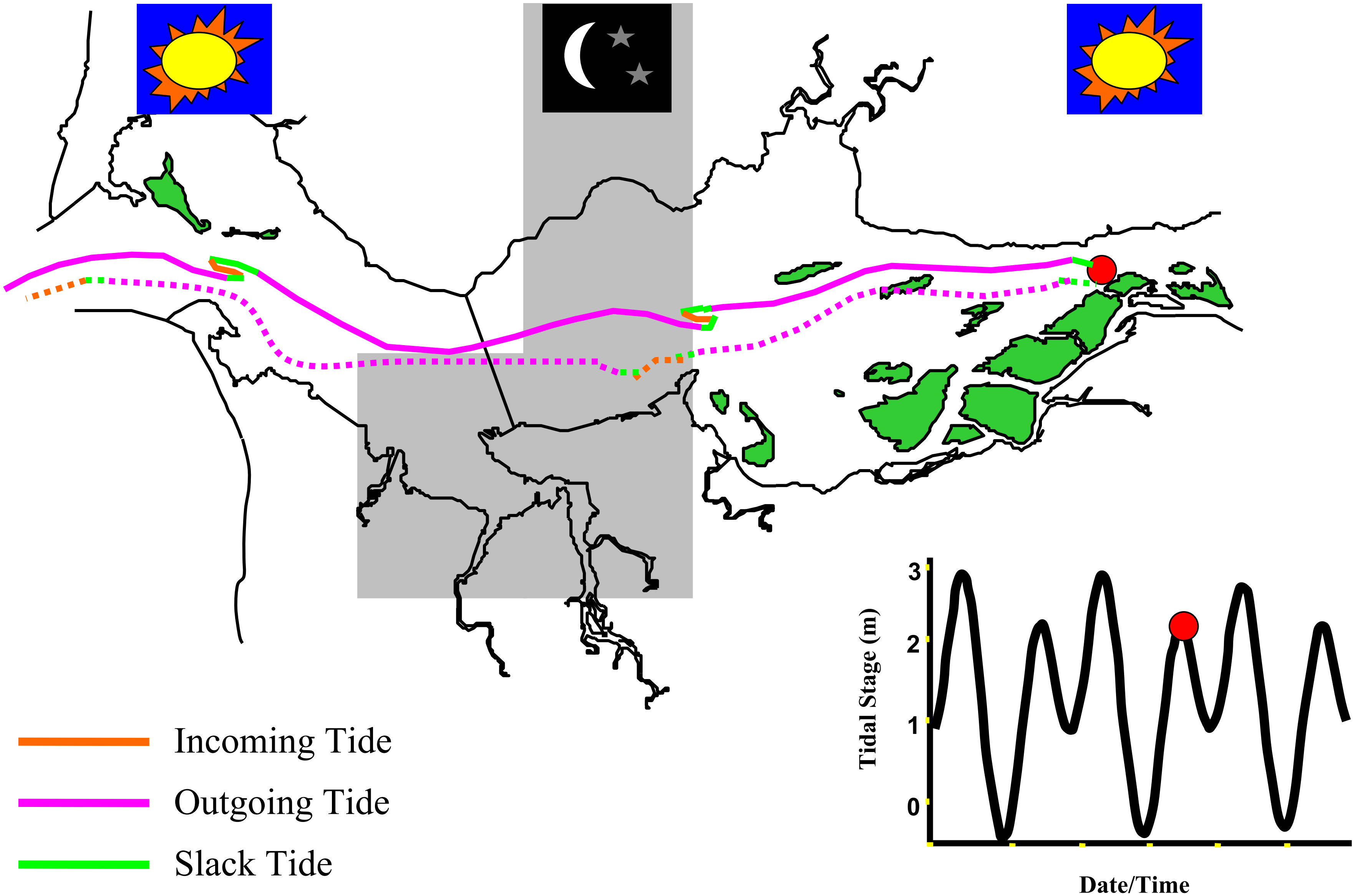


Figure 39. Simulated movements and holding patterns (colored line) for a spring/summer Chinook "fish" (solid lines) and steelhead (dashed lines) as related to the tidal cycle (see legend colors) and hours of daylight (depicted as a sun or moon and shading). The exact route within the estuary is not known, therefore, the path is drawn through the middle of the estuary. The smaller inset figure shows the tidal stage with a red dot at the location in the tide which the simulation begins, actual start time is May 5, 2004, at 3:05 pm. Simulated rates are based on the weighted average rate for spring Chinook in 2004 and steelhead 2002-2003.

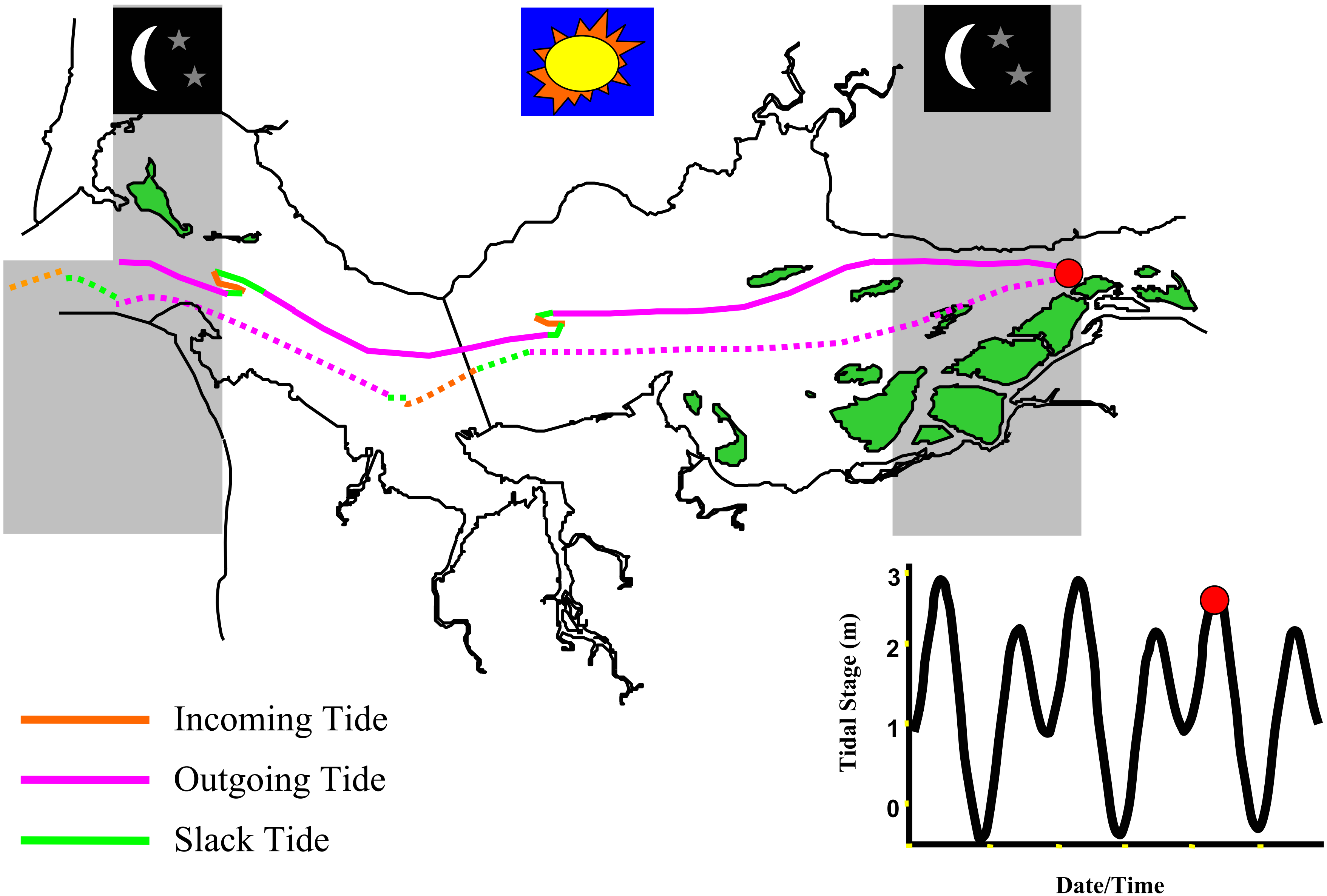


Figure 40. Simulated movements and holding patterns (colored line) for a spring/summer Chinook "fish" (solid lines) and steelhead (dashed lines) as related to the tidal cycle (see legend colors) and hours of daylight (depicted as a sun or moon). The exact route within the estuary is not known, therefore, the path is drawn through the middle of the estuary. The smaller inset figure shows the tidal stage with a red dot at the location in the tide which the simulation begins, actual start time is May 5, 2004, at 1:45 am. Simulated rates are based on the weighted average rate for spring Chinook in 2004 and steelhead 2002-2003.

Table 27. Comparison of the difference in migration times from Jim Crow Point (rkm 46) to the ocean between simulated and real fish for five of the releases of spring/summer Chinook in 2004.

Release Date	Total # Real Fish	# of simulated fish within 3 h of real fish	% of simulated fish within 3 h of real fish	# of simulated fish within 6 h of real fish	% of simulated fish within 6 h of real fish
3-May	29	13	44.8	16	55.2
4-May	45	9	20.0	14	31.1
16-May	37	14	37.8	17	45.9
18-May	43	15	34.9	21	48.8
28-May	56	16	28.6	23	41.1
Pooled	210	67	31.9	91	43.3

There is also the potential of releasing fish in more upriver locations, such as Longview, WA; however the further upriver the release location, the more dependent management is on modeling of fish movements and the positive effects may be reduced compared with estuarine releases. More data on fish movements (boat tracks) should be collected to refine modeled movements of fish in the estuary if alternate release locations in the estuary were to be implemented.

There is a concern that releasing fish directly in the estuary would reduce the residence time in the river, which fish may need to further adapt to a saltwater environment. However, the migration time between Bonneville to the release site is typically very rapid (~ 3-5 days) for all species; hence this short time period would likely be insufficient for significant physiological development.

If the lack of proper smolt development is a concern, then a more appropriate decision would be whether or not to transport fish, rather than where. Such a strategy is supported by our assessment of fish condition of various stocks. In addition, it might be unwise to transport fish at times when environmental conditions are particularly stressful. For example, fall Chinook appear to experience deteriorated physiological condition during periods of warm water in the Snake/Columbia system. Barging fish could exacerbate this situation compared to ROR fish that could perhaps avoid such thermal extremes behaviorally by migrating below thermoclines. This hypothesis needs to be addressed.

Most importantly, we reiterate the point that there are huge effects of day of release (and passage at BON for ROR fish) on their chances of successfully entering the ocean. If this effect is due to daily variation in fish quality or environmental (including barges) conditions or both is as yet unknown. However, the implications for this daily variation are vast. This is a critically important point for trying to figure out how to increase survival of either barged or ROR fish. Daily variation in survival estimates is exceptionally confounding for trying to tease patterns of either delayed mortality or SARs out of tag-return data. Individual releases over the course of a run should not be thought of as pseudoreplicates (sensu Hurlbert 1984), let alone replicates.

ACKNOWLEDGMENTS

We would like to thank the U.S. Army Corps of Engineers, Walla Walla District for funding this research. Rebecca Kalamasz, Paul Ocker, Karen Zelch, Scott Dunmire, and Ann Setter of the U.S. Army Corps of Engineers provided guidance and support. This report would not be possible without the dedication of previous project leaders, Larry Davis, Tom Stahl, Shaun Clements, and Dave Jepsen. Nathan Truelove provided essential data and information on the CORIE model. Jennifer Ramsay and Tracey Momoda provided helpful comments. Our seasonal field-crew members provided valuable time and energy. Drs. Alix Gitelman and Cliff Pereira provided useful advice on statistics. Russell Perry and Dr. John Skalski were extremely helpful in answering our questions regarding survival models. Numerous individuals, named in past years' reports, provided essential technical expertise and support.

LITERATURE CITED

Baptista, A.M., Y. Zhang, A. Chawla, M. Zulauf, C. Seaton, E.P. Myers III, J. Kindle, M. Wilkin, M. Burla, and P.J. Turner. 2005. A cross-scale model for 3D baroclinic circulation in estuary-plume-shelf systems: II. Application to the Columbia River. Continental Shelf Research. 25:935-972.

Beckman, B.R., D.A. Larsen, C. Sharpe, B. Lee-Pawlak, C.B. Schreck, and W.W. Dickhoff. 2000. Physiological status of naturally reared juvenile spring Chinook salmon in the Yakima River: seasonal dynamics and changes associated with smolting. Transactions of the American Fisheries Society. 129:727-753.

Beeman, J. W., T. C. Robinson, P. V. Haner, S. P. Vanderkooi and A.G. Maule. 1999. Gas bubble disease monitoring and research of juvenile salmonids. USGR/BRD Report to Bonneville Power Administration, Project No. 96-021, Contract No. 96AI93279.

Birtwell, I. K. and G. M. Kruzynski. 1989. In situ and laboratory studies on the behaviour and survival of Pacific salmon (genus *Oncorhynchus*). Hydrobiologia. 188-198:543-560.

Brown, R.S., S.J. Cooke, W.G. Anderson, and R.S. McKinley. 1999. Evidence to challenge the "2% rule" for biotelemetry. North American Journal of Fisheries Management. 19:867-871.

Budy, P., G.P. Thiede, N. Bouwes, C.E. Petrosky, and H. Schaller. 2002. Evidence linking delayed mortality of Snake River salmon to their earlier hydrosystem experience. North American Journal of Fisheries Management. 22:35-51.

Burnham, K. P., D. R. Anderson, G. C. White, C. Brownie, and K. H. Pollock. 1987. Design and analysis methods for fish survival experiments based on release-recapture. American Fisheries Society Monograph. 5:1–437.

Congleton, J.L., W.J. LaVoie, C.B. Schreck, L.E., Davis, H. Lorz, and C. Slater. 1996. Evaluation of procedures for collection, bypass, and downstream passage of outmigrating salmonids. Annual Report to the Walla Walla District U.S. Army Corps of Engineers, Walla Walla, Washington.

Cormack, R. M. 1964. Estimates of survival from the sightings of marked animals. Biometrika. 51:429–438.

Dickhoff, W.W., B.R. Beckman, D.A., Larsen, C.V.W. Mahnken, C.B. Schreck, C. Sharpe, and W.S. Zaugg. 1995. Quality assessment of hatchery-reared spring Chinook salmon smolts in the Columbia River basin. American Fisheries Society Symposium. 15:292-302.

Giorgi, A.E., G.A. Swan, and W.S. Zaugg. 1988. Susceptibility of Chinook salmon smolts to bypass systems at hydroelectric dams. North American Journal of Fisheries Management. 8:25-29.

Glabek, J.H., B.A., Ryan, W.P. Nunnallee, and J.W. Ferguson. 2003. Detection of passive integrated transponder (PIT) tags on piscivorous bird colonies in the Columbia River Basin, 2001. Draft report to the U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington.

Hamilton, P. 1990. Modeling salinity and circulation for the Columbia River Estuary. Progress in Oceanography. 25:113-156.

Hockersmith, E.E., W.D. Muir, G.S. Steven, and B.P. Sandford. 2003. Comparison of migration rate and survival between radio-tagged and PIT-tagged migrant yearling Chinook salmon in the Snake and Columbia Rivers. North American Journal of Fisheries Management. 23:404-413.

Hoffarth, P. 2000. Thermal gradients, collection, and mortality at the McNary project, 1999. Annual Report to the U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington.

Hurlbert, S.H. 1984. Pseudoreplication and the design of ecological field experiments. Ecological Monographs. 54:187-211.

Jarvi, T. 1989. The effect of osmotic stress on the anti-predatory behaviour of Atlantic salmon smolts: a test of the 'maladaptive anti-predator behaviour' hypothesis. Nordic Journal of Freshwater Research. 65:71-79.

Jepsen, D.B., S.P. Clements, M.D. Karnowski, C.B. Schreck. *In preparation*. Migration and survival of transported and run-of-river juvenile salmonids in the lower Columbia River.

Jepsen, N., C. Schreck, S. Clements, and E.B. Thorstad. *In Press*. A brief discussion on the 2% tag/body weight rule of thumb. Aquatic Telemetry: Advances and Applications.

Jolly, G. M. 1965. Explicit estimates from capture-recapture data with both death and immigration–stochastic model. Biometrika. 52:225–247.

Kelsey, D.A., C.B. Schreck, J.L. Congleton, and L.E. Davis. 2002. Effects of juvenile steelhead on juvenile Chinook behavior and physiology. Transactions of the American Fisheries Society. 131:676–689.

Ledgerwood, R.D., B.A. Ryan, E.P. Nunnallee, and J.W. Ferguson. 1998. Estuarine recovery of PIT-tagged juvenile salmonids from the Lower Granite Dam Transportation Study, 1998. Annual Report to the U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington.

Moore, A., I. C. Russell, and E. C. E Potter. 1990. The effects of intraperitoneally implanted dummy acoustic transmitters on the behaviour and physiology of juvenile Atlantic salmon, *Salmo salar* L. Journal of Fish Biology. 37: 713-721.

Perry, R.W., S.D. Fielding, A.C. Cochran, J.L. Schei, J.M. Sprando, G.T. George, N.S. Adams, and D.W. Rondorf. 2003. Turbine survival and migration behavior of subyearling Chinook salmon at McNary Dam, 2003. Final Report of Research by the U. S. Geological Survey to the U.S. Department of Energy, Bonneville Power Administration, Contract 00014243, Portland, Oregon.

Peven, C., A. Giorgi, J. Skalski, M. Langeslay, A. Grassell, S. G. Smith, T. Counihan, R. Perry, and S. Bickford. 2005. Guidelines and recommended protocols for conducting, analyzing, and reporting juvenile salmonid survival studies in the Columbia River basin. Report to the U.S. Army Corps of Engineers, Portland, Oregon.

Plumb, J.M., A.C. Braatz, J.N. Lucchesi, S.D. Fielding, A.D. Cochran, T.K. Nation, J.M. Sprando, J.L Schei, R.W. Perry, N.S. Adams, and D.W. Rondorf. 2004. Behavior and survival of radio-tagged juvenile Chinook salmon and steelhead relative to the performance of a removable spillway weir at Lower Granite Dam, Washington, 2003. Annual Report by the U.S. Geological Survey to the Army Corps of Engineers, contract W68SBV00104592, Walla Walla, Washington.

Roby, D.D., K. Collis, D.E. Lyons, D.P. Craig, J. Adkins, A.M. Myers, and R.M. Suryan. 2002. Effects of colony relocation on diet and productivity of Caspian terns. Journal of Wildlife Management. 66: 662–673.

Ryan, B.A., S.G. Smith, J.M. Butzerin, and J.W. Ferguson. 2003. Relative vulnerability to avian predation of juvenile salmonids tagged with passive integrated transponders in the Columbia River estuary, 1998-2000. Transactions of the American Fisheries Society. 132:275-288.

Schreck, C.B., S. Kaattari, L.E. Davis, C.E. Pearson, P.A. Wood, J.L. Congleton. 1993. Evaluation of the facilities for collection, bypass, and transportation of outmigrating Chinook salmon. Annual Report 1993, Project JTF-92-XX-3. U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington.

Schreck, C.B., L.E. Davis, D. Kelsey, P.A. Wood, J.L. Congleton, B. LaVoie, T. Mosey, S. Rocklage, and B. Sun. 1994. Evaluation of facilities for collection, bypass, and transportation of outmigrating Chinook salmon. Draft Annual Report 1994, Project JTF-92-XX-3. U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington.

Schreck, C.B., L.E. Davis, D. Kelsey, J.L. Congleton, and W.J. LaVoie. 1995. Evaluation of facilities for collection, bypass, and transportation of outmigrating Chinook salmon. Draft Annual Report for 1995, Project JTF-92-XX-3. U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington.

Schreck, C.B., L.E. Davis, and C.S. Price. 1996. Evaluation of procedures for collection, bypass, and transportation of outmigrating Chinook salmon. Draft Annual Report for 1996, Project MPE-96-10, prepared for the U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington.

Schreck, C.B., L.E. Davis, and C. Seals. 1997. Evaluation of migration and survival of juvenile salmonids following transportation. Draft Annual Report 1997, Project MPE-95-3. U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington.

Schreck, C.B., and T.P. Stahl. 1998. Evaluation of migration and survival of juvenile salmonids following transportation. Draft Annual Report 1998, Project MPE-W-97-4. U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington.

Schreck, C.B., T.P. Stahl, and M.D. Karnowski. 2000. Evaluation of migration and survival of juvenile steelhead following transportation. Draft Annual Report 2000, Project TPE-00-1. U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington.

Schreck, C.B., D. B. Jepsen, S. Clements, and M. D. Karnowski. 2001*a*. Evaluation of migration and survival of juvenile steelhead and fall Chinook following transportation. Draft Annual Report 2001, Project TPE-00-1. U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington.

Schreck, C.B., M. D. Karnowski, S. Clements, and D.B. Jepsen. 2001*b*. Evaluation of delayed mortality of juvenile salmonids in the near ocean environment following passage through the Columbia River hydrosystem. Draft Annual Report 2001, Project BPS-00-01. U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington.

Schreck, C. B., D. D. Roby, S. Clements, and M. D. Karnowski. 2001*c*. Juvenile salmonid survival in specific areas of the Nehalem Watershed. Draft 2001 Annual Report to Oregon Watershed Enhancement Board.

Schreck, C.B., D. B. Jepsen, S. Clements, and M. D. Karnowski. 2002*a*. Evaluation of migration and survival of juvenile steelhead and fall Chinook following transportation. Draft Annual Report 2002, Project TPE-00-1. U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington.

Schreck, C.B., M. D. Karnowski, S. Clements, and D.B. Jepsen. 2002*b*. Evaluation of delayed mortality of juvenile salmonids in the near ocean environment following passage through the Columbia River hydrosystem. Draft Annual Report 2001, Project BPS-00-01. U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington.

Schreck, C.B., S. P. Clements, M. D. Karnowski, and D. B. Jepsen,. 2003*a*. Evaluation of migration and survival of juvenile steelhead following transportation. Draft Annual Report 2003, Project TPE-00-1, Objective 2C, prepared for the U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington.

Schreck, C.B., S. P. Clements, M. D. Karnowski, and D. B. Jepsen,. 2003*b*. Evaluation of migration and survival of juvenile fall Chinook following transportation. Draft Annual Report 2003, Project TPE-00-1, Objective 2C, prepared for the U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington.

Seals-Price, C., and C. B. Schreck. 2003*a*. Stress and saltwater-entry behavior of juvenile Chinook salmon (*Oncorhynchus tshawytscha)*: conflicts in physiological motivation. Canadian Journal of Fisheries and Aquatic Sciences. 60:910-918.

Seals-Price, C., and C. B. Schreck. 2003*b*. Effects of bacterial kidney disease on saltwater preference of juvenile spring Chinook salmon, *Oncorhynchus tshawytscha*. Aquaculture. 222:331-341.

Seber, G. A. F. 1965. A note on the multiple recapture census. Biometrika. 52:249–259.

Simenstad, C. A., L. F. Small, C. D. McIntire, D. A. Jay, and C. Sherwood. 1990. Columbia River Estuary studies: An introduction to the estuary, a brief history, and prior studies. Progress in Oceanography. 25:1-13.

Skalski, J. R., J. Lady, R. Townsend, A. E. Giorgi, J. R. Stevenson, C. M. Peven, and R. D. McDonald. 2001. Estimating in-river survival of migrating salmonid smolts using radio-telemetry. Canadian Journal of Fisheries and Aquatic Sciences. 58:1887-1997.

Smith, S. G., J. R. Skalski, W. Schlechte, A. Hoffmann, and V. Cassen. 1994. Statistical survival analysis of fish and wildlife tagging studies. SURPH.1 Manual. (Available from University of Washington, School of Aquatic & Fisheries Science, 1325 Fourth Avenue, Suite 1820, Seattle, WA 98101-2509).

Sokal, R. R. and F. J. Rohlf. 1981. Biometry. W. H. Freeman and Company, San Francisco.

Ward, D.L. and L.M. Miller. 1989. Using radiotelemetry in fisheries investigations. Oregon Department of Fish and Wildlife (Fish Division) Information Reports No. 88-7.

Appendix 1

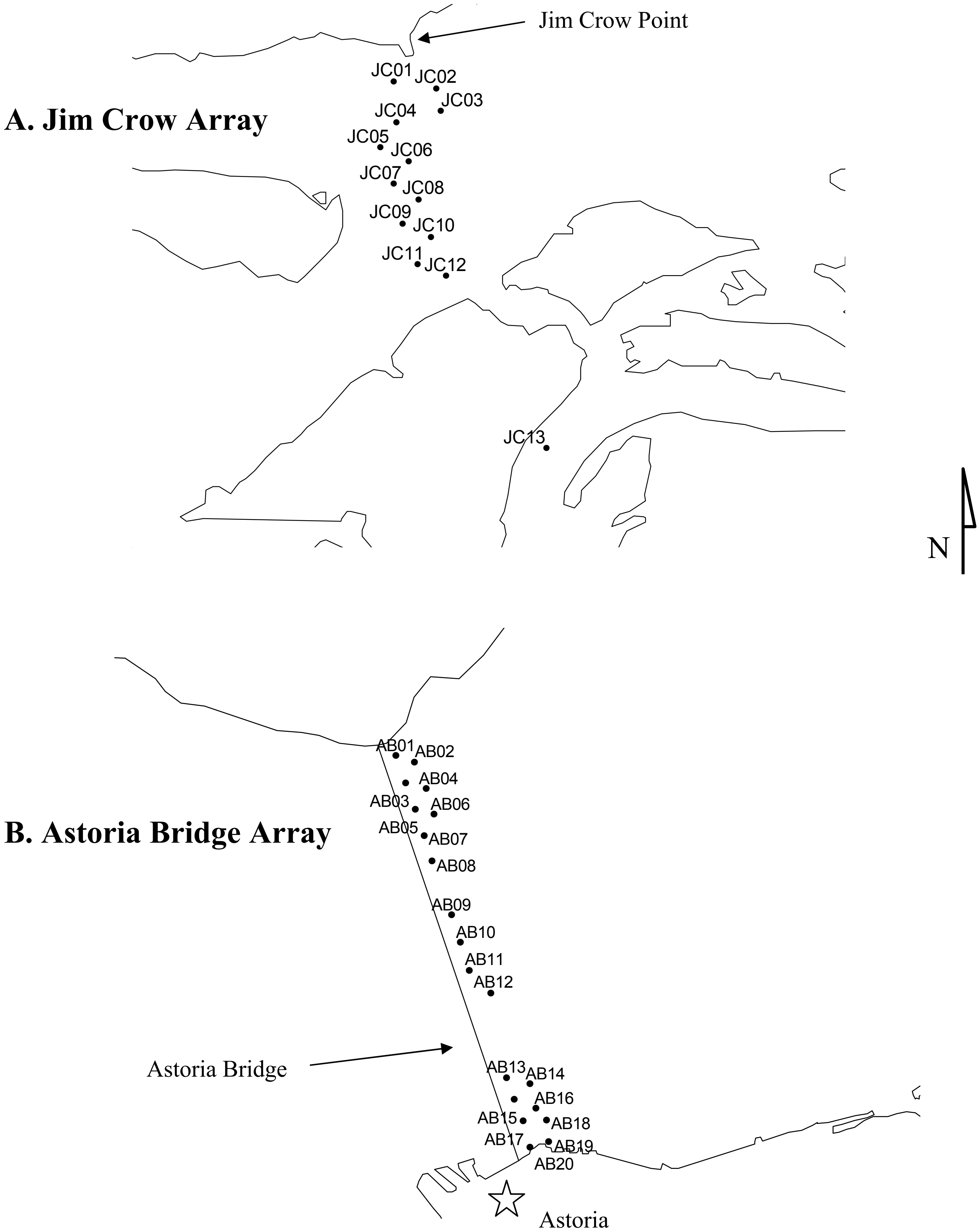
Appendix 1, Table 1. Status of each individual buoy-receiver system in the Ocean Array for each of the three clusters of releases in the 2004 season. Blank spaces indicate that there were no problems (lost or damaged) for the respective receiver. If a receiver was lost or broken, then the data for that given release would have been lost, unless otherwise noted. It is presumed that the cause of moved and lost systems is shipping traffic. Broken receivers were damaged when retrieving for downloads. For the location of specific receiver numbers, see Figure 2 of Appendix 1.

Site	May 3 and 4 Releases	May 16 and 18 Releases	May 28 and 29 Releases
O01			Broken
O02			
O03			
O04			
O05			
O06			
O07			
O08	Broken *		
O09			
O10			
O11			
O12			
O13			Lost
O14			
O15			
O16			
O17			
O18	Lost *		
O19			Moved out of position
O20			Lost
O21			
O22			Broken
O23			
O24			
O25			
O26			
O27	Moved to O28		
O28	Lost		
O29	Lost *		
O30	Lost		Moved out of position **
O31			
O32			
O33	Lost *		
O34	Lost *	Lost *	
O35	Lost		
O36			
O37			
O38		Lost	Moved out of position **

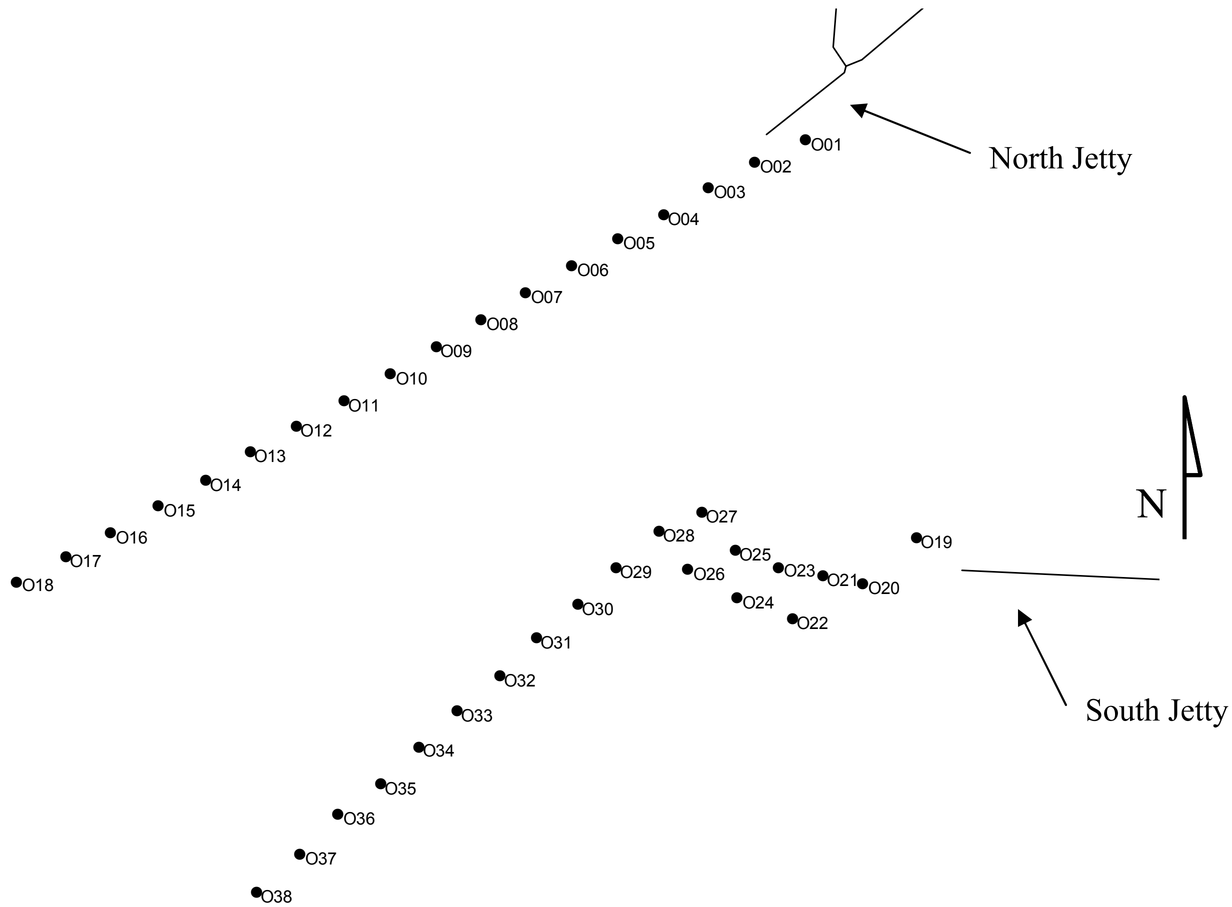
* Receiver was lost or broken after being downloaded near the end of fish passage for a given release; although it is possible that some fish were missed at the end of a release.

** Receiver-buoy systems moved after being downloaded near the end of fish passage for a given release.

Appendix 1, Figure 1. Buoy-receiver numbering at the (A) Jim Crow Array and the (B) Astoria Bridge Array in 2004.



Appendix 1, Figure 2. Buoy-receiver numbering at the Ocean Array in 2004.



Appendix 1, Table 2. The number of spring/summer Chinook released and the number of individual detections at each array on each of the six releases. Actual detections and the detections after the numbers are adjusted for downstream detections (fish detected downstream but were missed by an upstream array) are shown for 2004.

Release Date	# Fish Released	# of individual detections Actual		# of individual detections Includes missed fish	
5/3/04	114	Jim Crow	66	Jim Crow	74
		Seal	2		
		Rice	19		
		Bridge	46	Bridge	50
		Ocean	31		
5/4/04	164	Jim Crow	109	Jim Crow	123
		Seal	9		
		Rice	30		
		Bridge	75	Bridge	86
		Ocean	54		
5/16/04	141	Jim Crow	97	Jim Crow	101
		Seal	11		
		Rice	19		
		Bridge	71	Bridge	72
		Ocean	40		
5/18/04	132	Jim Crow	84	Jim Crow	92
		Seal	6		
		Rice	16		
		Bridge	64	Bridge	65
		Ocean	49		
5/28/04	102	Jim Crow	80	Jim Crow	94
		Seal	2		
		Rice	24		
		Bridge	85	Bridge	90
		Ocean	67		
5/29/04	110	Jim Crow	82	Jim Crow	100
		Seal	3		
		Rice	38		
		Bridge	85	Bridge	93
		Ocean	72		
Pooled Releases	763	Jim Crow	518	Jim Crow	584
		Seal	33		
		Rice	146		
		Bridge	426	Bridge	456
		Ocean	313		

Appendix 1, Table 3. Survival probabilities (S) for acoustic-tagged smolts, as generated by the SURPH model (Smith et al. 1994) where SH = Steelhead, FC = fall Chinook, and SC = spring/summer Chinook. For the different sites, JC = Jim Crow (rkm 46), and AB = Astoria Bridge (rkm 22), and SI = Sand Island (rkm 8). When SURPH estimates were not available (due to extremely high or low detection probabilities), simple arithmetic was used to approximate these estimates (denoted by 'M'). The weight of survival probabilities for the JC Array is also given. *Pooled barged hatchery and wild fish.

Year	Species	Release	Type	$S_{arrayJC}$	$S_{arrayAB}$	$S_{arraySI}$	λ	Weight
2001	SH	1	BRG	0.519 (0.086)		0.550 (0.111)	1.000 (0.000)	
		1	ROR	0.780 (0.076)		0.769 (0.083)	1.000 (0.000)	105.3
		2	BRG	0.111^{M} (****)				
		2	ROR	0.415 (0.084)		0.643 (0.128)	1.000 (0.000)	24.2
2002	SH	1	BRG	0.946 (0.034)	0.843 (0.073)	0.885 (0.107)	0.652 (0.099)	760.0
		1	ROR	0.870 (0.059)	0.879 (0.078)	0.927 (0.107)	0.846 (0.100)	214.5
		2	BRG	0.829 (0.055)	0.846 (0.066)	0.809 (0.101)	0.846 (0.100)	223.8
		2	ROR	0.806 (0.059)	0.875 (0.060)	0.815 (0.084)	0.923 (0.074)	188.4
		3	BRG	0.740 (0.067)	0.909 (0.068)	1.090 (0.244)	0.545 (0.150)	122.7
		3	ROR	0.853 (0.066)	0.899 (0.131)	0.880 (0.307)	0.444 (0.166)	165.8
2003	SH	1A	BRG	0.475 (0.079)	0.516 (0.132)	0.714 (0.171)	0.714 (0.171)	36.2
		1A	ROR	0.962 (0.058)	0.850 (0.073)	0.881 (0.068)	0.793 (0.075)	279.7
		1B	BRG	0.827 (0.054)	0.740 (0.064)	0.761 (0.065)	0.912 (0.049)	232.0
		1B	ROR	0.948 (0.127)	0.619 (0.111)	0.779 (0.095)	0.700 (0.102)	55.7
		2A	BRG	0.890 (0.048)	0.896 (0.050)	0.996 (0.031)	0.771 (0.071)	340.6
		2A	ROR	0.576 (0.076)	0.715 (0.094)	0.854 (0.086)	0.813 (0.098)	56.9
		2B	BRG*	0.917 (0.029)	0.941 (0.027)	0.952 (0.031)	0.829 (0.045)	992.1
			Hatch	0.910 (0.041)	0.932 (0.039)	0.942 (0.040)	0.795 (0.065)	
			Wild	0.924 (0.041)	0.951 (0.037)	0.953 (0.046)	0.871 (0.060)	
		2B	ROR	0.444 (0.082)	0.762 (0.111)	0.884 (0.128)	0.600 (0.155)	29.7
		3A	BRG*	0.849 (0.043)	0.823 (0.051)		0.706 (0.064)	386.2
			Hatch	0.931 (0.038)	0.834 (0.057)		0.718 (0.072)	
			Wild	0.664 (0.102)	0.786 (0.110)		0.667 (0.136)	
		3A	ROR	0.794 (0.066)	0.882 (0.107)		0.429 (0.094)	145.0
		3B	BRG*	0.853 (0.045)	0.792 (0.058)		0.500 (0.072)	366.2
			Hatch	0.955 (0.036)	0.851 (0.061)		0.553 (0.081)	
			Wild	0.640 (0.096)	0.625 (0.121)		0.300 (0.145)	
		3B	ROR	0.687 (0.113)	0.566 (0.136)		0.545 (0.150)	37.2
2004	SC	1A	BRG	0.658 (0.049)	0.704 (0.065)		0.587 (0.073)	182.5
		1B	BRG	0.772 (0.038)	0.744 (0.054)		0.573 (0.057)	415.3
		2A	BRG	0.728 (0.039)	0.709 (0.048)		0.549 (0.059)	347.0
		2B	BRG	0.726 (0.043)	0.682 (0.051)		0.750 (0.054)	280.9
		3A	BRG	0.917 (0.028)	0.982 (0.024)		0.729 (0.048)	1041.9
		3B	BRG	0.924 (0.029)	0.940 (0.034)		0.753 (0.047)	1037.4

Appendix 1, Table 4. Detection probabilities (P) for acoustic-tagged smolts, as generated by the SURPH model (Smith et al. 1994) where SH = Steelhead, FC = fall Chinook, and SC = spring/summer Chinook. For the different sites, JC = Jim Crow (rkm 46), and AB = Astoria Bridge (rkm 22), and SI = Sand Island (rkm 8). *Pooled barged hatchery and wild fish.

Year	Species	Release	Type	$P_{arrayJC}$	$P_{arrayAB}$	$P_{arraySI}$
2001	SH	1	BRG	0.786 (0.110)		0.429 (0.132)
		1	ROR	0.667 (0.086)		0.333 (0.086)
		2	BRG			
		2	ROR	0.750 (0.125)		0.333 (0.136)
2002	SH	1	BRG	0.973 (0.027)	0.677 (0.084)	0.652 (0.099)
		1	ROR	0.862 (0.064)	0.654 (0.093)	0.458 (0.102)
		2	BRG	0.941 (0.040)	0.885 (0.063)	0.458 (0.102)
		2	ROR	0.912 (0.049)	0.926 (0.050)	0.462 (0.098)
		3	BRG	0.931 (0.047)	0.826 (0.079)	0.333 (0.111)
		3	ROR	0.774 (0.075)	0.600 (0.110)	0.267 (0.114)
2003	SH	1A	BRG	1.000 (0.000)	0.714 (0.171)	1.000 (0.000)
		1A	ROR	0.615 (0.078)	0.824 (0.065)	0.821 (0.072)
		1B	BRG	0.771 (0.061)	0.919 (0.045)	0.912 (0.049)
		1B	ROR	0.464 (0.094)	0.818 (0.082)	0.875 (0.083)
		2A	BRG	0.872 (0.054)	0.947 (0.036)	0.900 (0.055)
		2A	ROR	0.850 (0.080)	0.941 (0.057)	0.929 (0.069)
		2B	BRG*	0.884 (0.035)	0.963 (0.021)	0.853 (0.043)
			Hatch	0.909 (0.043)	0.976 (0.024)	0.939 (0.042)
			Wild	0.857 (0.054)	0.949 (0.035)	0.771 (0.071)
		2B	ROR	0.923 (0.074)	0.909 (0.087)	0.857 (0.132)
		3A	BRG*	0.942 (0.032)	0.973 (0.027)	
			Hatch	0.950 (0.034)	0.966 (0.034)	
			Wild	0.917 (0.080)	1.000 (0.000)	
		3A	ROR	0.806 (0.071)	0.800 (0.103)	
		3B	BRG*	0.918 (0.039)	0.960 (0.039)	
			Hatch	0.897 (0.049)	0.955 (0.044)	
			Wild	1.000 (0.000)	1.000 (0.000)	
		3B	ROR	0.750 (0.125)	0.857 (0.132)	
2004	SC	1A	BRG	0.880 (0.046)	0.871 (0.060)	
		1B	BRG	0.860 (0.037)	0.796 (0.055)	
		2A	BRG	0.944 (0.027)	0.975 (0.025)	
		2B	BRG	0.877 (0.041)	0.980 (0.020)	
		3A	BRG	0.856 (0.037)	0.925 (0.032)	
		3B	BRG	0.806 (0.041)	0.889 (0.037)	

Appendix 1, Table 5. Results of goodness of fit tests (Burnham tests 2 and 3, Burnham et al. 1987) for acoustic tag releases where SH = Steelhead and SC = spring/summer Chinook. *Pooled barged hatchery and wild fish. For each year, critical values (α = 0.05) were adjusted via the Dunn-Šidák method (Sokal and Rohlf 1981). This resulted in ά = 0.0127 for 2001, ά = 0.0085 for 2002, ά = 0.0043 for 2003 (BRG and ROR only; k = 12 releases), ά = 0.0034 for 2003 (hatchery and wild BRG and ROR; k = 15 releases) and ά = 0.0085 for 2004. If no adjustments were used, the probability of committing one Type I error would be 0.1855 for 2001, 0.2649 for 2002, 0.4596 for 2003 (BRG and ROR), 0.5367 for 2003 (hatchery and wild BRG and ROR) and 0.2649 for 2004.

				Test 2				Test 3			
Year	**Species**	**Release**	**Type**	**df**	X^2	**p**	**Fisher's p**	**df**	X^2	**p**	**Fisher's p**
2001	SH	1	BRG	1	0.0000	1.0000	1.0000	*a*	*a*	*a*	*a*
		1	ROR	1	2.2700	0.1320	0.1008	*a*	*a*	*a*	*a*
		2	BRG	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*
		2	ROR	1	0.0000	1.0000	1.0000	*a*	*a*	*a*	*a*
2002	SH	1	BRG	3	0.3900	0.9432	---	*a*	*a*	*a*	*a*
		1	ROR	3	3.0600	0.3817	---	3	1.11	0.7747	---
		2	BRG	**3**	**16.5200**	**0.0009**	---	*a*	*a*	*a*	*a*
		2	ROR	3	0.6700	0.8804	---	*a*	*a*	*a*	*a*
		3	BRG	3	0.5506	0.9076	---	*a*	*a*	*a*	*a*
		3	ROR	3	0.2352	0.9717	---	3	1.20	0.7524	---
2003	SH	1A	BRG	*a*	*a*	*a*	*a*	1	0.18	0.6732	0.4723
		1A	ROR	3	2.5700	0.4631	---	1	0.09	0.7633	0.5841
		1B	BRG	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*
		1B	ROR	*a*	*a*	*a*	*a*	1	0.00	1.0000	1.0000
		2A	BRG	*a*	*a*	*a*	*a*	1	0.00	1.0000	1.0000
		2A	ROR	*a*	*a*	*a*	*a*	**1**	**3.65**	**0.0562**	**0.0414**
		2B	BRG*	3	7.9600	0.0468	---	*a*	*a*	*a*	*a*
			Hatch	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*
			Wild	3	6.3000	0.0980	---	*a*	*a*	*a*	*a*
		2B	ROR	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*
		3A	BRG*	**1**	**3.6700**	**0.0554**	**0.0577**	1	1.52	0.2173	0.1058
			Hatch	**1**	**4.3700**	**0.0365**	**0.0500**	1	1.58	0.2090	0.1052
			Wild	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*
		3A	ROR	1	0.0000	1.0000	0.4883	1	0.00	1.0000	1.0000
		3B	BRG*	1	0.0000	1.0000	1.0000	*a*	*a*	*a*	*a*
			Hatch	1	0.0000	1.0000	1.0000	*a*	*a*	*a*	*a*
			Wild	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*
		3B	ROR	1	0.0000	1.0000	1.0000	1	0.00	1.0000	1.0000
2004	SC	1A	BRG	1	0.0000	0.9744	0.4105	1	1.91	0.1675	0.1437
		1B	BRG	1	0.8100	0.3685	0.1786	1	0.06	0.8070	0.7244
		2A	BRG	1	0.0000	1.0000	1.0000	1	0.10	0.7541	0.6217
		2B	BRG	1	0.0000	1.0000	1.0000	1	0.00	1.0000	1.0000
		3A	BRG	1	0.0800	0.7711	1.0000	1	0.48	0.4900	0.4991
		3B	BRG	1	0.9600	0.3264	0.3467	1	0.00	1.0000	1.0000

a The test statistic was not calculable due to the presence of only zeroes in rows or columns of contingency tables.

Appendix 1, Table 6. Survival estimates (S) and detection probabilities (P) for radio-tagged smolts, as generated by the SURPH model (Smith et al. 1994) where SH = Steelhead, FC = fall Chinook, and SC = spring/summer Chinook. For the different sites, ST = Stella (rkm 89), and JC = Jim Crow (rkm 46). When SURPH estimates were not available (due to extremely high or low detection probabilities), simple arithmetic was used to approximate these estimates (denoted by 'M'). For a given year, the simple arithmetic estimates were within ± 2.9 % of the SURPH estimates. The weight of survival probabilities for the ST Array is also given. *Pooled barged hatchery and wild fish, *** data not available.

Year	Species	Release	Type	S_{ST}	S_{JC}	P_{ST}	P_{JC}	$Weight_{ST}$
2002	SH	1	BRG*	0.799 (0.088)	---	0.790 (0.094)	---	82
			LGR H	0.938 (0.105)	---	0.800 (0.127)	---	80
			LGR W	0.750 (0.168)	---	0.800 (0.179)	---	20
			MCN H	0.711 (0.200)	---	0.750 (0.217)	---	13
		1	ROR	1 (0)	---	1 (0)	---	***
		2	BRG*	0.734 (0.064)	---	0.936 (0.044)	---	133
			LGR H	0.752 (0.101)	---	0.846 (0.100)	---	56
			LGR W	0.857 (0.094)	---	1(0)	---	84
			MCN H	0.600 (0.127)	---	1(0)	---	22
		2	ROR	1.021 (0.025)	---	0.909 (0.087)	---	1,669
		3	BRG*	0.871 (0.038)	---	0.905 (0.037)	---	514
			LGR H	0.836 (0.068)	---	0.950 (0.049)	---	152
			LGR W	0.981 (0.075)	---	0.790 (0.094)	---	170
			MCN H	0.829 (0.066)	---	0.958 (0.041)	---	158
		3	ROR	0.974 (0.025)	---	1 (0)	---	1,483
2002	FC	1	BRG	0.800 (0.195)	---	0.625 (0.171)	---	380
		1	ROR	0.933 (0.09)	---	0.857 (0.094)	---	80
		2	BRG	0.817 (0.085)	---	0.790 (0.094)	---	72
		2	ROR	1.083 (0.082)	---	0.762 (0.093)	---	67
		3	BRG	0.604 (0.082)	---	0.929 (0.069)	---	67
		3	ROR	1.008 (0.034)	---	0.923 (0.052)	---	11
2003	SH	1A	BRG	0.926 (0.031)	0.940 (0.030)	0.760 (0.048)	0.985 (0.015)	887
		1A	ROR	0.954 (0.038)	0.892 (0.051)	0.825 (0.060)	1 (0)	627
		1B	BRG	0.878 ^{M}(***)	1.000 (****)	0 ^{M}(0)	0.927 (0.032)	***
		1B	ROR	0.872 (0.049)	1.023 (0.014)	0.024 (0.024)	0.882 (0.055)	321
		2A	BRG*	0.946 (0.024)	0.968 (0.020)	0.988 (0.012)	0.949 (0.025)	1565
			Hatch	0.936 (0.036)	1.005 (0.004)	0.977 (0.023)	0.905 (0.045)	688
			Wild	0.955 (0.031)	0.929 (0.040)	1 (0)	1 (0)	924
		2A	ROR	0.478 (0.074)	1.008 (0.009)	0.864 (0.073)	0.947 (0.051)	42
		2B	BRG*	0.947 (0.023)	0.993 (0.012)	1 (0)	0.894 (0.033)	1680
			Hatch	0.936 (0.036)	0.981 (0.023)	1 (0)	0.857 (0.054)	688
			Wild	0.957 (0.029)	1.003 (0.003)	1 (0)	0.930 (0.039)	1,060
		2B	ROR	0.541 (0.082)	0.950 (0.049)	1 (0)	0.947 (0.051)	44
		3A	BRG*	0.935 (0.026)	0.989 (0.012)	0.965 (0.020)	0.976 (0.017)	1314
			Hatch	0.984 (0.017)	0.983 (0.018)	0.965 (0.024)	0.982 (0.018)	3,429
			Wild	0.849 (0.062)	1 (0)	0.964 (0.035)	0.964 (0.035)	185
		3A	ROR	0.588 (0.073)	0.962 (0.038)	0.962 (0.038)	1 (0)	65
		3B	BRG*	0.913 (0.029)	1.001 (0.001)	1 (0)	0.963 (0.021)	964
			Hatch	0.921 (0.034)	1.002 (0.002)	1 (0)	0.946 (0.030)	729
			Wild	0.897 (0.057)	1 (0)	1 (0)	1 (0)	251
		3B	ROR	0.797 (0.061)	0.955 (0.043)	0.97 (0.030)	0.807 (0.071)	171

Appendix 1, Table 6. (Continued) Survival estimates (S) and detection probabilities (P) for radio-tagged smolts, as generated by the SURPH model (Smith et al. 1994) where SH = Steelhead, FC = fall Chinook, and SC = spring/summer Chinook. For the different sites, ST = Stella (rkm 89), and JC = Jim Crow (rkm 46). When SURPH estimates were not available (due to extremely high or low detection probabilities), simple arithmetic was used to approximate these estimates (denoted by 'M'). For a given year, the simple arithmetic estimates were within ± 2.9 % of the SURPH estimates. The weight of survival probabilities for the ST Array is also given. *Pooled barged hatchery and wild fish, *** data not available.

Year	Species	Release	Type	S_{ST}	S_{JC}	P_{ST}	P_{JC}	Weight $_{ST}$
2003	FC	1A	BRG	0.728 (0.085)	0.873 (0.090)	0.842 (0.084)	0.813 (0.098)	73
		1A	ROR	0.797 (0.061)	0.993 (0.034)	0.941 (0.040)	0.833 (0.068)	171
		1B	BRG	0.831 (0.049)	0.871 (0.052)	1 (0)	0.914 (0.047)	290
		1B	ROR	0.716 (0.070)	0.958 (0.052)	0.964 (0.035)	0.833 (0.076)	105
		2A	BRG	0.359 (0.077)	1.006 (0.008)	0.143 (0.094)	0.923 (0.074)	22
		2A	ROR	0.888 (0.085)	0.874 (0.089)	0.433 (0.091)	0.893 (0.059)	110
		2B	BRG	0.549 (0.079)	0.775 (0.096)	0.889 (0.074)	0.765 (0.103)	48
		2B	ROR	0.826 (0.056)	1.002 (0.002)	0.974 (0.026)	0.972 (0.027)	218
		3A	BRG	0.044 (0.030)	1.000^{M} (****)	0.500 (0.354)	0 (0) ^{M}	2
		3A	ROR	0.766 (0.069)	0.908 (0.061)	0.962 (0.038)	0.870 (0.070)	122
		3B	BRG	0.049^{M} (****)	1.000^{M} (****)	0^{M} (0)	1 (0)	***
		3B	ROR	0.480 (0.129)	0.720 (0.210)	0.333 (0.122)	0.636 (0.145)	14
2004	SC	1A	BRG	0.899 (0.03)	0.977 (0.016)	0.989 (0.011)	1 (0)	881
		1B	BRG	0.934 (0.026)	0.995 (0.059)	0.933 (0.027)	0.938 (0.061)	1,342
		2A	BRG	0.939 (0.026)	0.877 (0.046)	0.938 (0.027)	0.96 (0.039)	1,284
		2B	BRG	0.929 (0.028)	1.190 (0.149)	0.924 (0.03)	0.64 (0.096)	1,093
		3A	BRG	0.959 (0.02)	1.143 (0.130)	1 (0)	0.8 (0.103)	2,253
		3B	BRG	0.918 (0.028)	0.900 (0.032)	1 (0)	1 (0)	1,099

Appendix 1, Table 7. Results of goodness of fit tests (Burnham tests 2 and 3, Burnham et al. 1987) for radio tag releases where SH = Steelhead, FC = Fall Chinook, and SC = spring/summer Chinook. *Pooled barged hatchery and wild fish. For each year, critical values (α = 0.05) were adjusted via the Dunn-Šidák method (Sokal and Rohlf 1981). This resulted in ά = 0.0085 for 2002 steelhead (BRG and ROR; k = 6 releases), ά = 0.0043 for 2002 steelhead (hatchery and wild, MCN and LGR BRG and ROR; k = 12 releases), ά = 0.0085 for 2002 fall Chinook, ά = 0.0043 for 2003 steelhead (BRG and ROR; k = 12 releases), ά = 0.0032 for 2003 steelhead (hatchery and wild BRG and ROR; k = 16 releases), ά = 0.0043 for 2003 fall Chinook, and ά = 0.0085 for 2004 spring/summer Chinook. If no adjustments were used, the probability of committing one Type I error would be 0.2649 for 2002 steelhead (6 releases), 0.4596 for 2002 steelhead (12 releases), 0.2649 for 2002 fall Chinook, 0.4596 for 2003 steelhead (12 releases), 0.5599 for 2003 steelhead (16 releases), 0.4596 for 2003 fall Chinook, and 0.2649 for 2004 spring/summer Chinook.

				Test 2				**Test 3**			
Year	**Species**	**Release**	**Type**	**df**	**X^2**	**p**	**Fisher's p**	**df**	**X^2**	**p**	**Fisher's p**
2002	SH	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*
2002	FC	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*
2003	SH	1A	BRG	1	0.00	1.0000	1.0000	1	0.18	0.6732	0.4723
		1A	ROR	*b*	*b*	*b*	*b*	1	0.09	0.7633	0.5841
		1B	BRG	*b*	*b*	*b*	*b*	*b*	*b*	*b*	*b*
		1B	ROR	1	0.00	1.0000	1.0000	1	0.00	1.0000	1.0000
		2A	BRG*	1	0.00	1.0000	1.0000	1	0.00	1.0000	1.0000
			Hatch	1	0.00	1.0000	1.0000	1	0.00	1.0000	1.0000
			Wild	*b*	*b*	*b*	*b*	*b*	*b*	*b*	*b*
		2A	ROR	1	0.00	1.0000	1.0000	1	3.65	0.0562	0.4140
		2B	BRG*	*b*	*b*	*b*	*b*	*b*	*b*	*b*	*b*
			Hatch	*b*	*b*	*b*	*b*	*b*	*b*	*b*	*b*
			Wild	*b*	*b*	*b*	*b*	*b*	*b*	*b*	*b*
		2B	ROR	*b*	*b*	*b*	*b*	*b*	*b*	*b*	*b*
		3A	BRG*	1	0.00	1.0000	1.0000	1	1.52	0.2173	0.1058
			Hatch	1	0.00	1.0000	1.0000	1	1.58	0.2090	0.1052
			Wild	1	0.00	1.0000	1.0000	*b*	*b*	*b*	*b*
		3A	ROR	*b*	*b*	*b*	*b*	1	0.00	1.0000	1.0000
		3B	BRG*	*b*	*b*	*b*	*b*	*b*	*b*	*b*	*b*
			Hatch	*b*	*b*	*b*	*b*	*b*	*b*	*b*	*b*
			Wild	*b*	*b*	*b*	*b*	*b*	*b*	*b*	*b*
		3B	ROR	1	0.00	1.0000	1.0000	1	0.00	1.0000	1.0000
2003	FC	1A	BRG	**1**	**12.22**	**0.0005**	**0.0010**	*b*	*b*	*b*	*b*
		1A	ROR	1	0.00	1.0000	1.0000	1	0.00	1.0000	1.0000
		1B	BRG	*b*	*b*	*b*	*b*	*b*	*b*	*b*	*b*
		1B	ROR	1	0.00	1.0000	1.0000	1	0.00	1.0000	1.0000
		2A	BRG	1	0.00	1.0000	1.0000	1	0.00	1.0000	1.0000
		2A	ROR	1	0.06	0.8060	0.5645	1	0.00	1.0000	1.0000
		2B	BRG	**1**	**3.63**	**0.0569**	**0.0392**	*b*	*b*	*b*	*b*
		2B	ROR	1	0.00	1.0000	1.0000	1	0.00	1.0000	1.0000
		3A	BRG	*b*	*b*	*b*	*b*	*b*	*b*	*b*	*b*
		3A	ROR	1	1.51	0.2196	0.1154	*b*	*b*	*b*	*b*

Appendix 1, Table 7 (Continued). Results of goodness of fit tests (Burnham tests 2 and 3, Burnham et al. 1987) for radio tag releases where SH = Steelhead, FC = Fall Chinook, and SC = spring/summer Chinook. *Pooled barged hatchery and wild fish. For each year, critical values (α = 0.05) were adjusted via the Dunn-Šidák method (Sokal and Rohlf 1981). This resulted in ά = 0.0085 for 2002 steelhead (BRG and ROR; k = 6 releases), ά = 0.0043 for 2002 steelhead (hatchery and wild, MCN and LGR BRG and ROR; k = 12 releases), ά = 0.0085 for 2002 fall Chinook, ά = 0.0043 for 2003 steelhead (BRG and ROR; k = 12 releases), ά = 0.0032 for 2003 steelhead (hatchery and wild BRG and ROR; k = 16 releases), ά = 0.0043 for 2003 fall Chinook, and ά = 0.0085 for 2004 spring/summer Chinook. If no adjustments were used, the probability of committing one Type I error would be 0.2649 for 2002 steelhead (6 releases), 0.4596 for 2002 steelhead (12 releases), 0.2649 for 2002 fall Chinook, 0.4596 for 2003 steelhead (12 releases), 0.5599 for 2003 steelhead (16 releases), 0.4596 for 2003 fall Chinook, and 0.2649 for 2004 spring/summer Chinook.

					Test 2				**Test 3**		
Year	**Species**	**Release**	**Type**	**df**	**X^2**	**p**	**Fisher's p**	**df**	**X^2**	**p**	**Fisher's p**
		3B	BRG	*b*	*b*	*b*	*b*	*b*	*b*	*b*	*b*
		3B	ROR	1	1.07	0.3020	0.2308	1	0.00	1.0000	1.0000
2004	SC	1A	BRG	*b*	*b*	*b*	*b*	1	0.00	1.0000	1.0000
		1B	BRG	1	0.00	1.0000	1.0000	1	0.35	0.5566	0.5843
		2A	BRG	1	3.31	0.0689	0.0625	1	0.64	0.4249	0.3082
		2B	BRG	**1**	**5.90**	**0.0152**	**0.0177**	1	0.00	1.0000	0.5469
		3A	BRG	*b*	*b*	*b*	*b*	*b*	*b*	*b*	*b*
		3B	BRG	*b*	*b*	*b*	*b*	*b*	*b*	*b*	*b*

a Unable to perform tests 2 and 3 because the lack of receiver arrays precludes generation of m tables.
b The test statistic was not calculable due to the presence of only zeroes in rows or columns of contingency tables.

Appendix 1, Table 8. Annual survival estimates (S) and for acoustic-tagged smolts, as calculated by simple (equal weighted) and weighted (unequally weighted) averages, where SH = Steelhead, FC = fall Chinook, and SC = spring/summer Chinook. *Pooled barged hatchery and wild fish, **Only one release, therefore S for that release is given.

Year	Species	Type	Simple $S_{arrayJC}$	Weighted $S_{arrayJC}$	Simple $S_{arrayAB}$	Weighted $S_{arrayAB}$	Simple $S_{arraySI}$	Weighted $S_{arraySI}$
2001	SH	BRG	0.520**	0.520**			0.550**	0.550**
			(0.086)	(0.086)	---	---	(0.111)	(0.111)
		ROR	0.597	0.712			0.706	0.741
			(0.183)	(0.142)	---	---	(0.063)	(0.053)
2002	SH	BRG	0.838	0.899	0.866	0.869	0.928	0.880
			(0.060)	(0.051)	(0.022)	(0.022)	(0.084)	(0.063)
		ROR	0.843	0.844	0.885	0.879	0.874	0.866
			(0.019)	(0.019)	(0.007)	(0.005)	(0.033)	(0.039)
2003	SH	BRG*	0.802	0.876	0.785	0.891	0.856	0.958
			(0.067)	(0.027)	(0.061)	(0.032)	(0.069)	(0.035)
			0.932	0.935	0.872	0.894	0.942**	0.942**
		Hatch	(0.013)	(0.013)	(0.030)	(0.032)	(0.040)	(0.040)
			0.743	0.885	0.787	0.928	0.953**	0.953**
		Wild	(0.091)	(0.067)	(0.094)	(0.050)	(0.046)	(0.046)
		ROR	0.735	0.841	0.732	0.789	0.850	0.856
			(0.084)	(0.069)	(0.051)	(0.042)	(0.024)	(0.022)
2004	SC	BRG	0.788	0.851	0.794	0.912		
			(0.040)	(0.042)	(0.043)	(0.049)	---	---

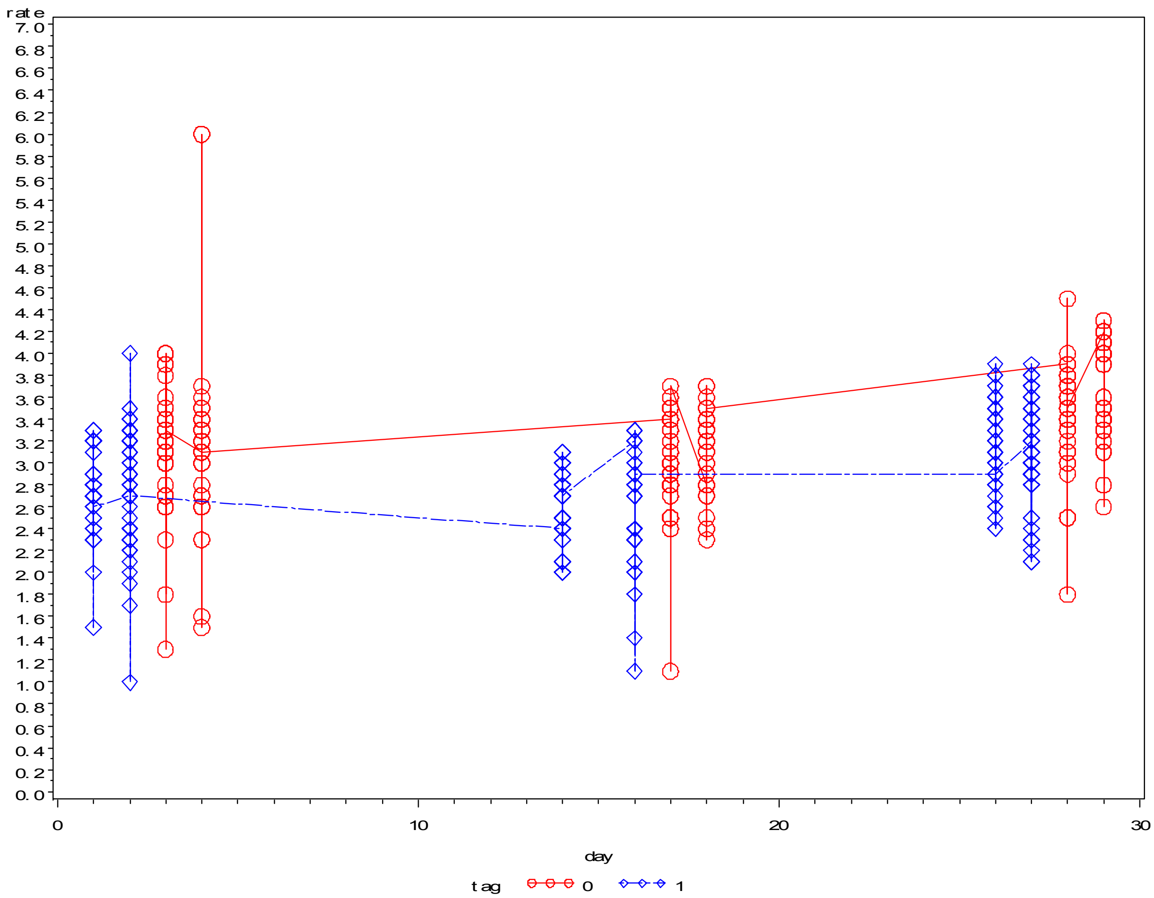
Appendix 1, Table 9. Annual survival estimates (S) and for radio-tagged smolts, as calculated by simple (equal weighted) and weighted (unequally weighted) averages, where SH = Steelhead, FC = fall Chinook, and SC = spring/summer Chinook; BRG = barged, ROR= Run-of-River, LGR = Lower Granite Dam, and MCN = McNary Dam. *Pooled barged hatchery and wild fish.

Year	Species	Type	$S_{STsimple}$	$S_{ST\ weighted}$	$S_{JCsimple}$	$S_{JCweighted}$
2002	SH	BRG*	0.801 (0.040)	0.838 (0.038)	---	---
		LGR H	0.842 (0.054)	0.819 (0.050)	---	---
		LGR W	0.863 (0.067)	0.872 (0.065)	---	---
		MCN H	0.713 (0.066)	0.783 (0.055)	---	---
		ROR	0.999 (0.014)	---	---	---
2002	FC	BRG	0.740 (0.068)	0.745 (0.070)	---	---
		ROR	1.008 (0.043)	1.012 (0.026)	---	---
2003	SH	BRG*	0.924 (0.011)	---	0.982 (0.010)	---
		Hatch	0.944 (0.014)	0.964 (0.015)	0.993 (0.006)	1.002 (0.001)
		Wild	0.914 (0.026)	0.942 (0.019)	0.983 (0.018)	---
		ROR	0.705 (0.080)	0.855 (0.059)	0.965 (0.020)	0.995 (0.011)
2003	FC	BRG	0.427 (0.137)	---	0.921 (0.039)	---
		ROR	0.745 (0.058)	0.783 (0.030)	0.909 (0.043)	1.000 (0.002)
2004	SC	BRG	0.930 (0.008)	0.933 (0.008)	1.013 (0.052)	0.946 (0.023)

Appendix 2

Migration Rate Analysis: Mixed Model Output

Appendix 2.A.1. **2004 spring/summer Chinook migration rate analyses: acoustic- versus radio-tagged fish**



Where 1 (diamonds) = acoustic-tagged fish and 0 (circles) = radio-tagged fish.

```
                     The Mixed Procedure

                      Model Information

Data Set                     WORK.MIGRATION2
Dependent Variable           rate
Covariance Structure         Variance Components
Estimation Method            REML
Residual Variance Method     Profile
Fixed Effects SE Method      Model-Based
Degrees of Freedom Method    Containment


                   Class Level Information

  Class      Levels    Values

  period          3    1 2 3
  tag             2    0 1


                         Dimensions
```

Covariance Parameters	3
Columns in X	12
Columns in Z	2
Subjects	1
Max Obs Per Subject	1013

Number of Observations

Number of Observations Read	1013
Number of Observations Used	1013
Number of Observations Not Used	0

Iteration History

Iteration	Evaluations	-2 Res Log Like	Criterion
0	1	1103.84089762	
1	3	1099.64199483	0.00005339
2	2	1099.62775303	0.00000561
3	1	1099.62553062	0.00000004
4	1	1099.62551413	0.00000000

Convergence criteria met.

Covariance Parameter Estimates

Cov Parm	Estimate
day	0.000395
flow	0.01104
Residual	0.1688

Fit Statistics

-2 Res Log Likelihood	1099.6
AIC (smaller is better)	1105.6
AICC (smaller is better)	1105.6
BIC (smaller is better)	1099.6

Type 3 Tests of Fixed Effects

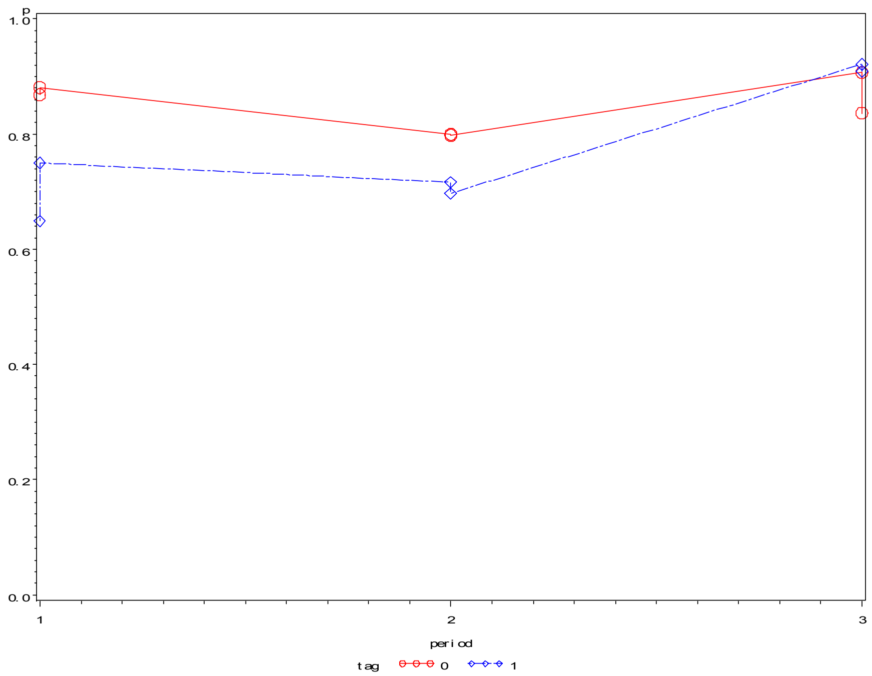
Effect	Num DF	Den DF	F Value	Pr > F
period	2	1005	21.55	<.0001
tag	1	1005	58.16	<.0001
period*tag	2	1005	3.98	0.0189

Least Squares Means

Effect	period	tag	Estimate	Standard Error	DF	t Value	Pr > |t|
period	1		2.3279	0.2812	1005	8.28	<.0001
period	2		1.9726	0.3447	1005	5.72	<.0001
period	3		2.1867	0.4919	1005	4.45	<.0001
tag		0	2.3255	0.3684	1005	6.31	<.0001
tag		1	1.9993	0.3377	1005	5.92	<.0001
period*tag	1	0	2.4313	0.3026	1005	8.04	<.0001
period*tag	1	1	2.2246	0.2619	1005	8.49	<.0001
period*tag	2	0	2.1640	0.3648	1005	5.93	<.0001
period*tag	2	1	1.7812	0.3261	1005	5.46	<.0001
period*tag	3	0	2.3814	0.5005	1005	4.76	<.0001
period*tag	3	1	1.9921	0.4848	1005	4.11	<.0001

Appendix 2.B.1. 2004 spring/summer Chinook: Survival to Jim Crow Point

Obs	period	tag	day	flow	y	n
1	1	1	1	5.5	74	114
2	1	1	2	6.4	123	164
3	1	0	3	7.1	86	99
4	1	0	4	7.0	89	101
5	2	1	14	6.7	101	141
6	2	1	16	6.3	92	132
7	2	0	17	7.1	80	100
8	2	0	18	7.1	79	99
9	3	1	26	8.2	94	102
10	3	1	27	8.7	100	110
11	3	0	28	7.9	88	97
12	3	0	29	8.7	82	98



Where 1 (diamond) = acoustic tag and 0 (circle) = radio tag

Model Information

Data Set	WORK.SURVIVAL2
Distribution	Binomial
Link Function	Logit
Response Variable (Events)	y
Response Variable (Trials)	n

Number of Observations Read	12
Number of Observations Used	12
Number of Events	1088
Number of Trials	1357

Class Level Information

Class	Levels	Values
period	3	1 2 3
tag	2	0 1

Criteria For Assessing Goodness Of Fit

Criterion	DF	Value	Value/DF
Deviance	5	1.2792	0.2558
Scaled Deviance	5	1.2792	0.2558
Pearson Chi-Square	5	1.2880	0.2576

```
Scaled Pearson X2          5         1.2880         0.2576
Log Likelihood                    -642.1032
```

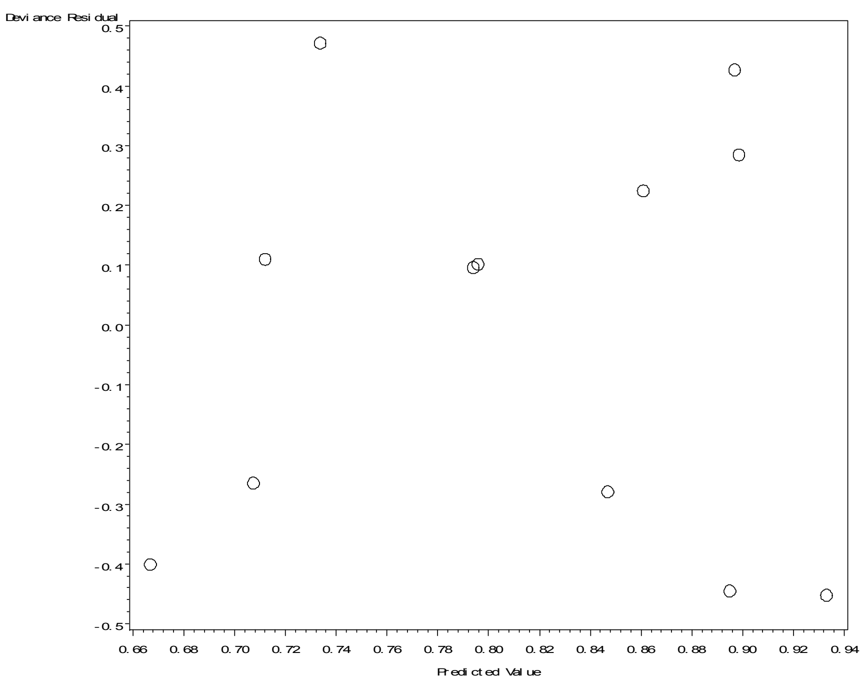
Algorithm converged.

Analysis Of Parameter Estimates

Parameter		DF	Estimate	Standard Error	Wald 95% Confidence Limits		Chi-Square	Pr > ChiSq
Intercept		1	14.8748	5.0856	4.9072	24.8423	8.56	0.0034
period	1	1	-14.5006	5.0045	-24.3092	-4.6920	8.40	0.0038
period	2	1	-13.8115	4.6739	-22.9721	-4.6508	8.73	0.0031
period	3	0	0.0000	0.0000	0.0000	0.0000	.	.
day		1	-0.4708	0.1867	-0.8368	-0.1048	6.36	0.0117
day*period	1	1	0.7907	0.1879	0.4225	1.1590	17.71	<.0001
day*period	2	1	0.4595	0.1690	0.1283	0.7908	7.39	0.0065
day*period	3	0	0.0000	0.0000	0.0000	0.0000	.	.
tag	0	1	0.4890	0.2809	-0.0616	1.0396	3.03	0.0818

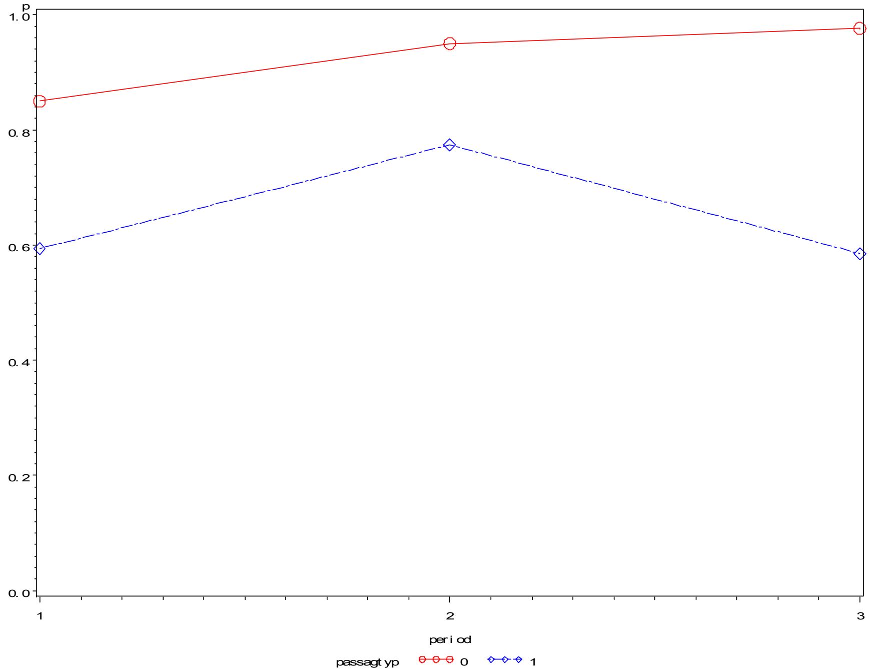
LR Statistics For Type 3 Analysis

Source	DF	Chi-Square	Pr > ChiSq
period	2	9.08	0.0107
day	1	0.20	0.6525
day*period	2	18.51	<.0001
tag	1	3.03	0.0819



Appendix 2.B.2. 2002 fall Chinook: Survival to Stella

Obs	period	passagtyp	day	flow	y	n
1	1	1	1	8.26	19	32
2	1	0	1	8.26	34	40
3	2	1	17	8.77	24	31
4	2	0	17	8.77	38	40
5	3	1	34	6.76	24	41
6	3	0	34	6.70	42	43



Where 1 (diamond) = BRG and 0 (circle) = ROR

Model Information

Data Set	WORK.SURVIVAL2
Distribution	Binomial
Link Function	Logit
Response Variable (Events)	y
Response Variable (Trials)	n

Number of Observations Read	6
Number of Observations Used	6
Number of Events	181
Number of Trials	227

Class Level Information

Class	Levels	Values
period	3	1 2 3
passagtyp	2	0 1

Criteria For Assessing Goodness Of Fit

Criterion	DF	Value	Value/DF
Deviance	1	0.1257	0.1257
Scaled Deviance	1	0.1257	0.1257
Pearson Chi-Square	1	0.1235	0.1235
Scaled Pearson X2	1	0.1235	0.1235
Log Likelihood		-95.6537	

Algorithm converged.

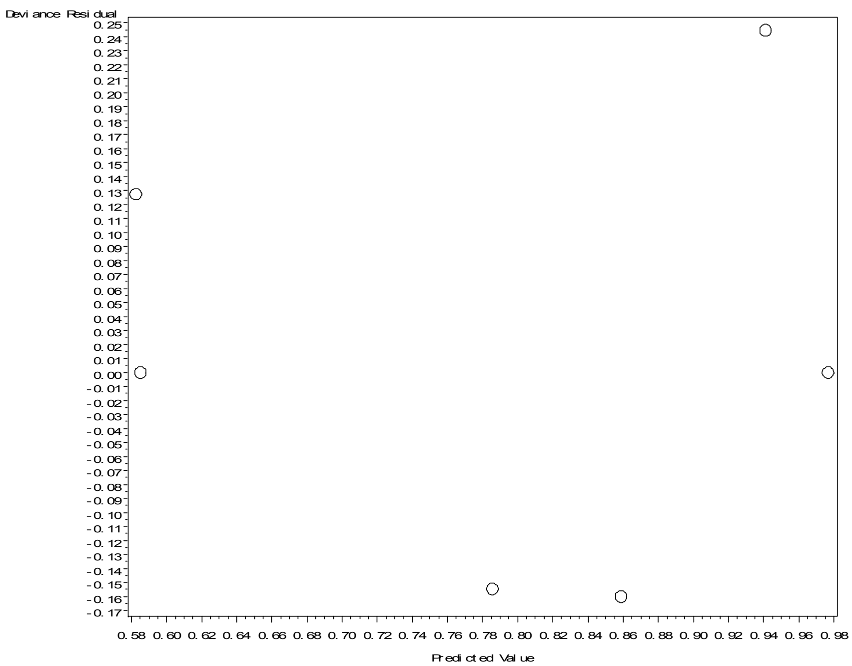
Analysis Of Parameter Estimates

Parameter		DF	Estimate	Standard Error	Wald 95% Confidence Limits		Chi-Square	Pr > ChiSq
Intercept		1	216.7064	130.5495	-39.1660	472.5787	2.76	0.0969
period	1	1	47.9980	29.1500	-9.1349	105.1309	2.71	0.0996
period	2	1	65.2865	38.9892	-11.1309	141.7038	2.80	0.0940
period	3	0	0.0000	0.0000	0.0000	0.0000	.	.

passagtyp	0	1	1.4725	0.4692	0.5529	2.3920	9.85	0.0017
passagtyp	1	0	0.0000	0.0000	0.0000	0.0000	.	.
flow		1	-32.0061	19.3248	-69.8821	5.8698	2.74	0.0977
Scale		0	1.0000	0.0000	1.0000	1.0000		

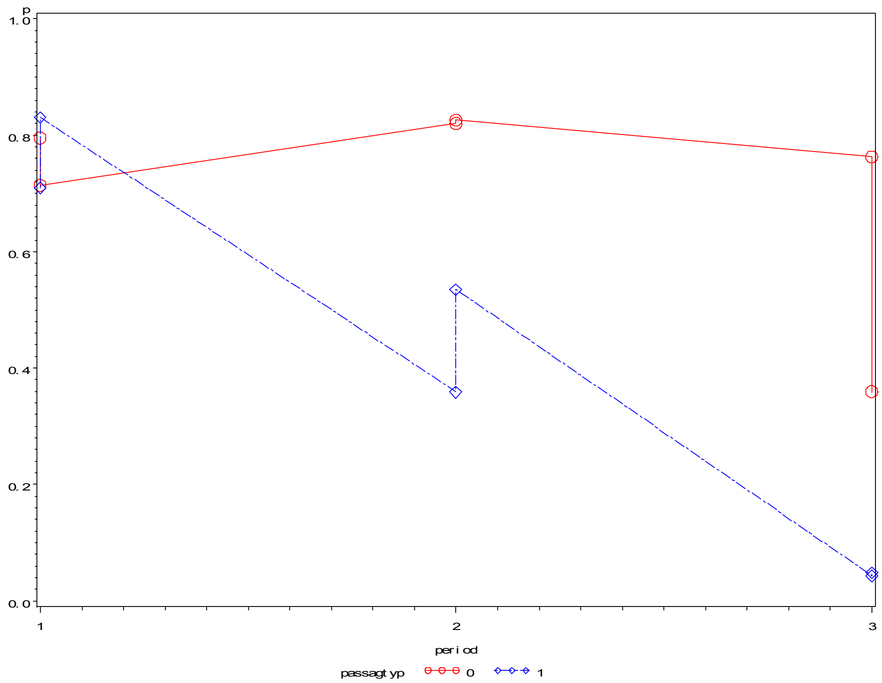
LR Statistics For Type 3 Analysis

Source	DF	Chi-Square	Pr > ChiSq
period	2	8.17	0.0168
passagtyp	1	10.91	0.0010
flow	1	3.67	0.0553



Appendix 2.B.3. 2003 fall Chinook: Survival to Stella

Obs	period	passagtyp	day	flow	y	n
1	1	1	1	8.09	22	31
2	1	0	1	8.04	35	44
3	1	1	3	7.89	49	59
4	1	0	3	7.89	30	42
5	2	1	22	6.53	14	39
6	2	0	22	6.53	32	39
7	2	1	24	5.84	23	43
8	2	0	24	5.74	38	46
9	3	1	42	5.23	2	46
10	3	0	42	5.22	29	38
11	3	1	44	3.62	2	41
12	3	0	44	3.62	18	50



Where 1 (diamond)= BRG and 0 (circle)= ROR

Model Information

Data Set	WORK.SURVIVAL2
Distribution	Binomial
Link Function	Logit
Response Variable (Events)	y
Response Variable (Trials)	n

Number of Observations Read	12
Number of Observations Used	12
Number of Events	294
Number of Trials	518

Class Level Information

Class	Levels	Values
period	3	1 2 3
passagtyp	2	0 1

Criteria For Assessing Goodness Of Fit

Criterion	DF	Value	Value/DF
Deviance	2	2.5599	1.2799
Scaled Deviance	2	2.0000	1.0000
Pearson Chi-Square	2	2.5794	1.2897
Scaled Pearson X2	2	2.0153	1.0076
Log Likelihood		-202.1067	

Algorithm converged.

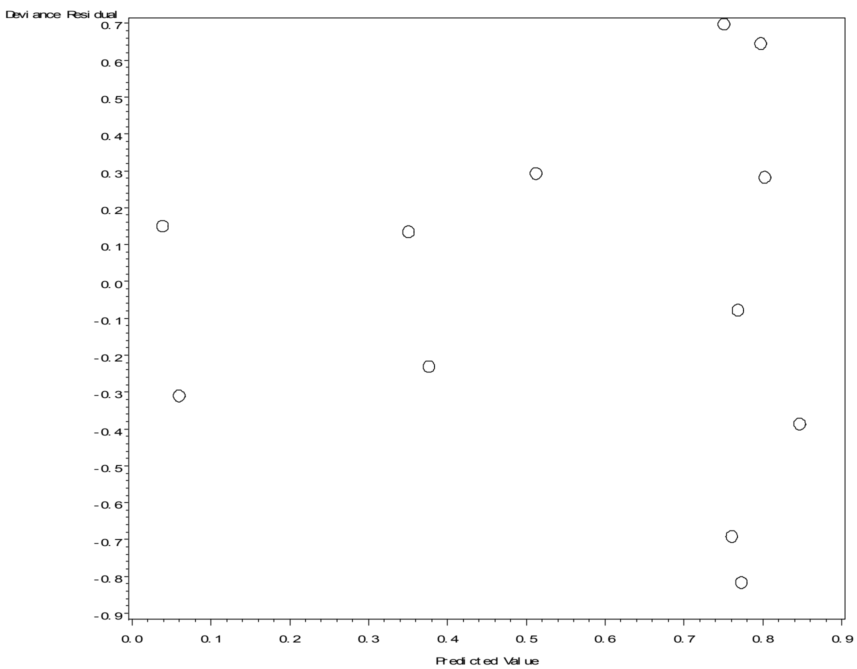
Analysis Of Parameter Estimates

Parameter		DF	Estimate	Standard Error	Wald 95% Confidence Limits		Chi-Square	Pr > ChiSq
Intercept		1	224.8429	270.3563	-305.046	754.7316	0.69	0.4056
period	1	1	-173.874	212.3486	-590.069	242.3220	0.67	0.4129
period	2	1	-145.546	167.8753	-474.575	183.4837	0.75	0.3859

period	3	0	0.0000	0.0000	0.0000	0.0000	.	.
day		1	-4.6722	5.5533	-15.5565	6.2121	0.71	0.4002
day*period	1	1	4.1367	4.9345	-5.5347	13.8081	0.70	0.4018
day*period	2	1	2.8504	3.0111	-3.0513	8.7520	0.90	0.3438
day*period	3	0	0.0000	0.0000	0.0000	0.0000	.	.
passagtyp	0	1	-14.0447	6.6633	-27.1045	-0.9849	4.44	0.0351

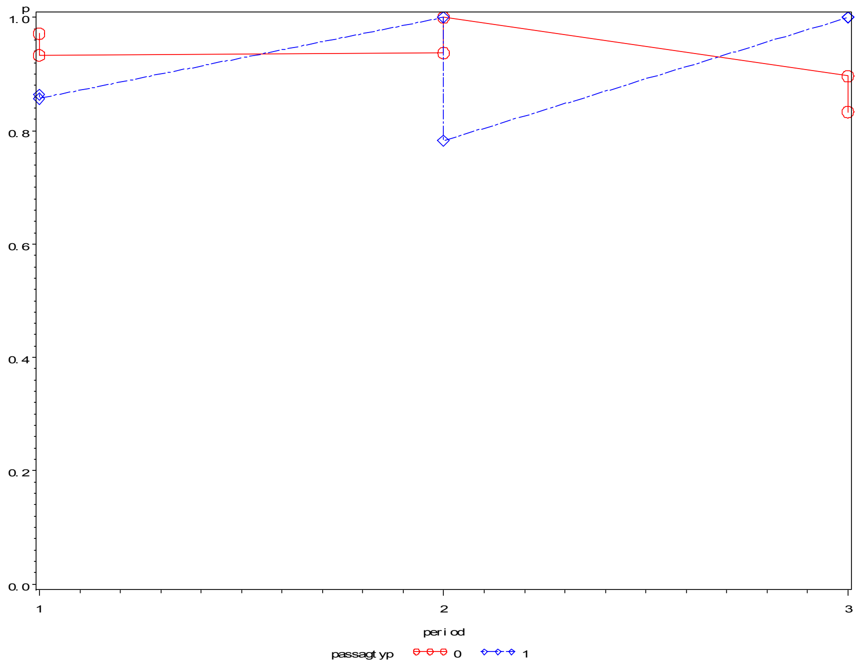
LR Statistics For Type 3 Analysis

Source	Num DF	Den DF	F Value	Pr > F	Chi-Square	Pr > ChiSq
period	2	2	1.46	0.4067	2.92	0.2325
day	1	2	0.59	0.5224	0.59	0.4420
day*period	2	2	1.16	0.4621	2.33	0.3123
passagtyp	1	2	4.14	0.1788	4.14	0.0418
flow	1	2	0.57	0.5306	0.57	0.4521
flow*passagtyp	1	2	4.00	0.1835	4.00	0.0455
day*passagtyp	1	2	9.71	0.0894	9.71	0.0018



Appendix 2.B.4. 2003 fall Chinook: Survival to Jim Crow

Obs	period	passagtyp	day	flow	y	n
1	1	1	1	8.09	19	22
2	1	0	1	8.04	34	35
3	1	1	3	7.89	42	49
4	1	0	3	7.89	28	30
5	2	1	22	6.53	14	14
6	2	0	22	6.53	30	32
7	2	1	24	5.84	18	23
8	2	0	24	5.74	38	38
9	3	1	42	5.23	2	2
10	3	0	42	5.22	26	29
11	3	1	44	3.62	2	2
12	3	0	44	3.62	15	18



Where 1 (diamond)= BRG and 0 (circle) = ROR

Model Information

Data Set	WORK.SURVIVAL2
Distribution	Binomial
Link Function	Logit
Response Variable (Events)	y
Response Variable (Trials)	n

Number of Observations Read	12
Number of Observations Used	12
Number of Events	268
Number of Trials	294

Class Level Information

Class	Levels	Values
period	3	1 2 3
passagtyp	2	0 1

Criteria For Assessing Goodness Of Fit

Criterion	DF	Value	Value/DF
Deviance	3	2.4755	0.8252
Scaled Deviance	3	2.4755	0.8252
Pearson Chi-Square	3	2.1070	0.7023
Scaled Pearson X2	3	2.1070	0.7023
Log Likelihood		-79.2642	

Algorithm converged.

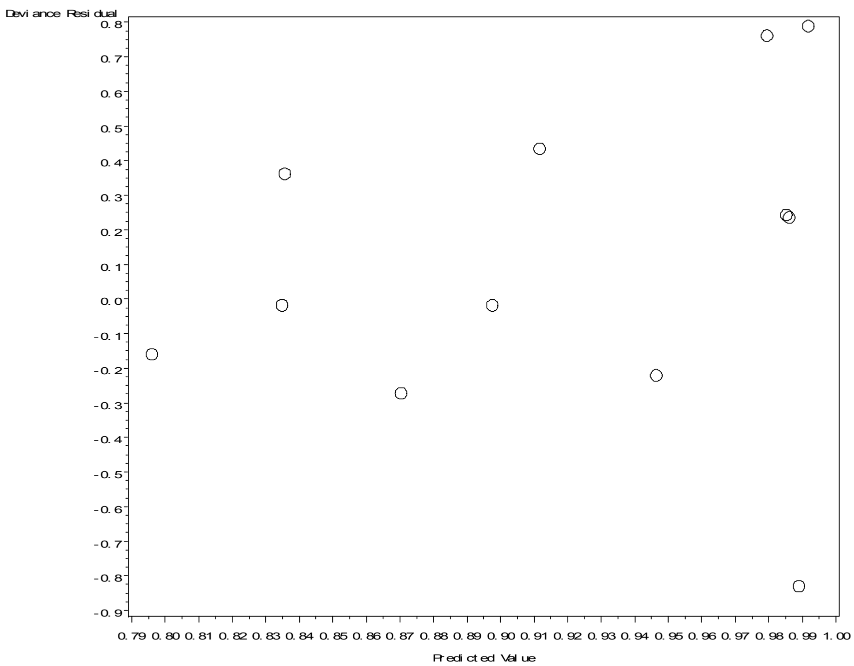
Analysis Of Parameter Estimates

Parameter		DF	Estimate	Standard Error	Wald 95% Confidence Limits		Chi-Square	Pr > ChiSq
Intercept		1	1791.476	799.9151	223.6710	3359.280	5.02	0.0251
period	1	1	-1414.79	631.4791	-2652.47	-177.113	5.02	0.0251
period	2	1	-1113.20	500.3045	-2093.78	-132.626	4.95	0.0261
period	3	0	0.0000	0.0000	0.0000	0.0000	.	.

day		1	-36.8494	16.4535	-69.0977	-4.6012	5.02	0.0251
day*period	1	1	32.4071	14.4809	4.0250	60.7892	5.01	0.0252
day*period	2	1	19.7924	8.9913	2.1699	37.4150	4.85	0.0277
day*period	3	0	0.0000	0.0000	0.0000	0.0000	.	.
passagtyp	0	1	0.6552	0.7994	-0.9117	2.2220	0.67	0.4125

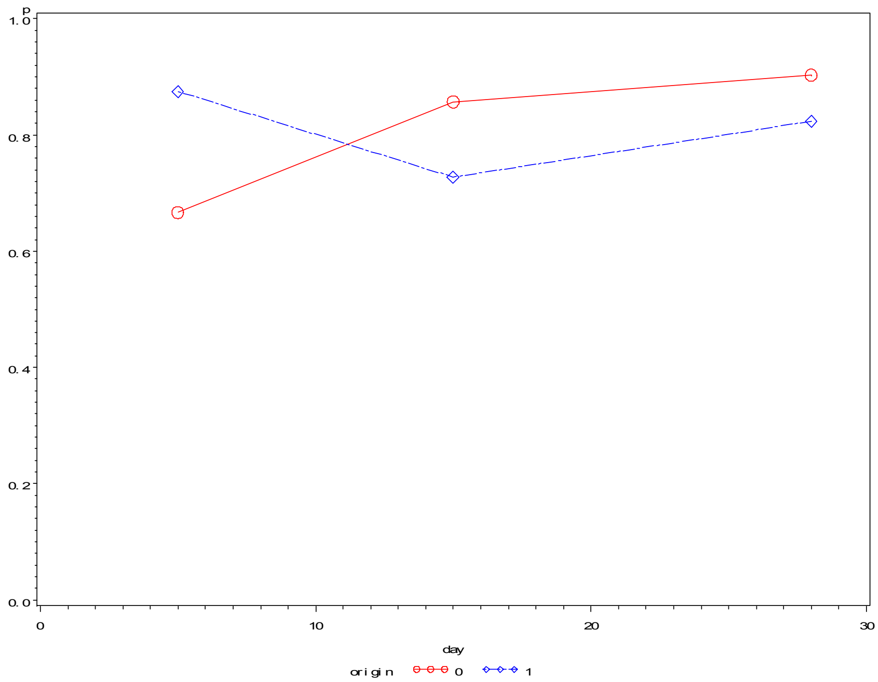
LR Statistics For Type 3 Analysis

Source	DF	Chi-Square	Pr > ChiSq
period	2	8.82	0.0121
day	1	8.65	0.0033
day*period	2	8.55	0.0139
passagtyp	1	0.71	0.3986
flow	1	8.43	0.0037
day*passagtyp	1	1.89	0.1698



Appendix 2.B.5. 2002 Steelhead: Survival to Stella (LGR hatchery vs. LGR wild)

Obs	period	origin	day	flow	y	n
1	1	1	5	6.96	14	16
2	1	0	5	6.96	10	15
3	2	1	15	6.61	16	22
4	2	0	15	6.61	12	14
5	3	1	28	8.78	28	34
6	3	0	28	8.78	28	31



Where 1 (diamond) = hatchery and 0 (circle) = wild

Model Information

Data Set	WORK.SURVIVAL2
Distribution	Binomial
Link Function	Logit
Response Variable (Events)	y
Response Variable (Trials)	n

Number of Observations Read	6
Number of Observations Used	6
Number of Events	108
Number of Trials	132

Class Level Information

Class	Levels	Values
period	3	1 2 3
origin	2	0 1

Criteria For Assessing Goodness Of Fit

Criterion	DF	Value	Value/DF
Deviance	2	1.6575	0.8288
Scaled Deviance	2	1.6575	0.8288
Pearson Chi-Square	2	1.6795	0.8397
Scaled Pearson X2	2	1.6795	0.8397
Log Likelihood		-60.7374	

Algorithm converged.

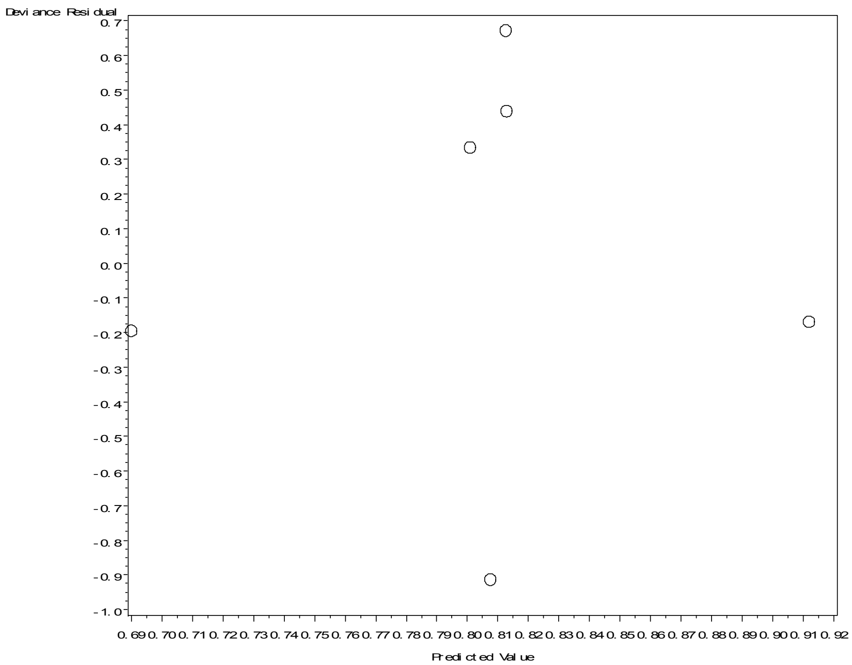
Analysis Of Parameter Estimates

Parameter		DF	Estimate	Standard Error	Wald 95% Confidence Limits		Chi-Square	Pr > ChiSq
Intercept		1	1.4831	0.6811	0.1483	2.8180	4.74	0.0294
day		1	-0.0032	0.0321	-0.0661	0.0596	0.01	0.9193
origin	0	1	-1.0170	0.9468	-2.8727	0.8387	1.15	0.2828
origin	1	0	0.0000	0.0000	0.0000	0.0000	.	.

day*origin	0	1	0.0701	0.0488	-0.0255	0.1657	2.07	0.1507
day*origin	1	0	0.0000	0.0000	0.0000	0.0000	.	.
Scale		0	1.0000	0.0000	1.0000	1.0000		

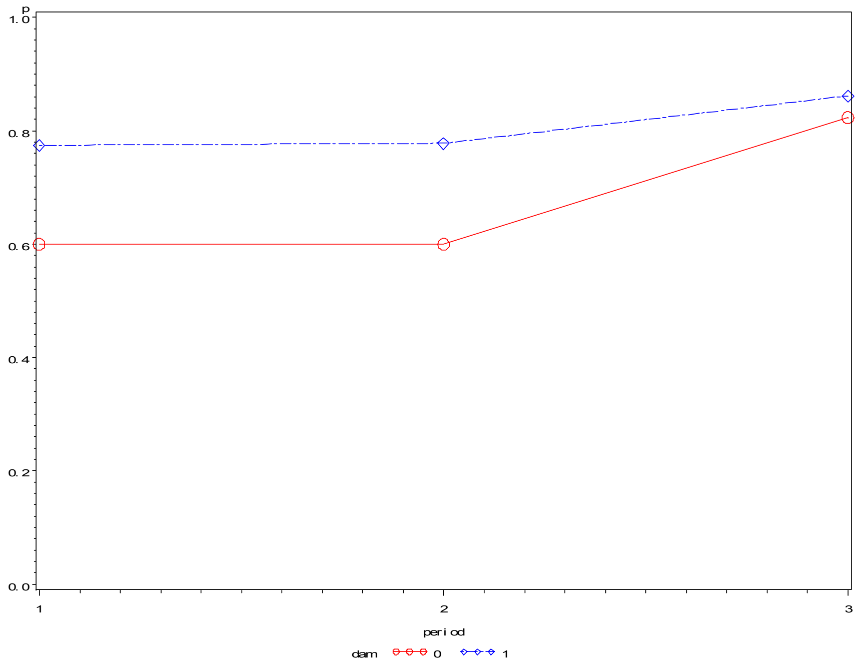
LR Statistics For Type 3 Analysis

Source	DF	Chi-Square	Pr > ChiSq
day	1	1.72	0.1898
origin	1	1.16	0.2807
day*origin	1	2.13	0.1443



Appendix 2.B.6. 2002 Steelhead: Survival to Stella (LGR H/W vs. McN hatchery)

Obs	period	dam	day	flow	y	n
1	1	1	5	6.96	24	31
2	1	0	5	6.96	9	15
3	2	1	15	6.61	28	36
4	2	0	15	6.61	9	15
5	3	1	28	8.78	56	65
6	3	0	28	8.78	28	34



Where 1 (diamond) = LGR and 0 (circle) = McN

Model Information

Data Set	WORK.SURVIVAL2
Distribution	Binomial
Link Function	Logit
Response Variable (Events)	y
Response Variable (Trials)	n

Number of Observations Read	6
Number of Observations Used	6
Number of Events	154
Number of Trials	196

Class Level Information

Class	Levels	Values
period	3	1 2 3
dam	2	0 1

Criteria For Assessing Goodness Of Fit

Criterion	DF	Value	Value/DF
Deviance	1	0.0062	0.0062
Scaled Deviance	1	0.0062	0.0062
Pearson Chi-Square	1	0.0062	0.0062
Scaled Pearson X2	1	0.0062	0.0062
Log Likelihood		-97.8063	

Algorithm converged.

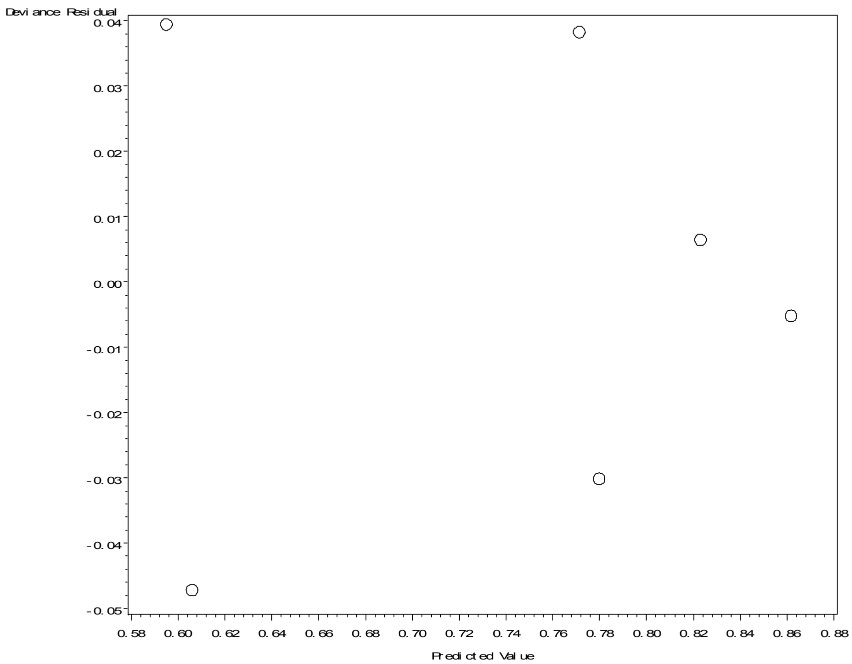
Analysis Of Parameter Estimates

Parameter		DF	Estimate	Standard Error	Wald 95% Confidence Limits		Chi-Square	Pr > ChiSq
Intercept		1	-0.1714	2.3498	-4.7770	4.4343	0.01	0.9419
day		1	0.0116	0.0355	-0.0580	0.0812	0.11	0.7440
dam	0	1	-2.6704	2.8278	-8.2127	2.8720	0.89	0.3450
dam	1	0	0.0000	0.0000	0.0000	0.0000	.	.
flow		1	0.1910	0.3683	-0.5310	0.9129	0.27	0.6042

flow*dam	0	1	0.2708	0.3695	-0.4533	0.9950	0.54	0.4635
flow*dam	1	0	0.0000	0.0000	0.0000	0.0000	.	.
Scale		0	1.0000	0.0000	1.0000	1.0000		

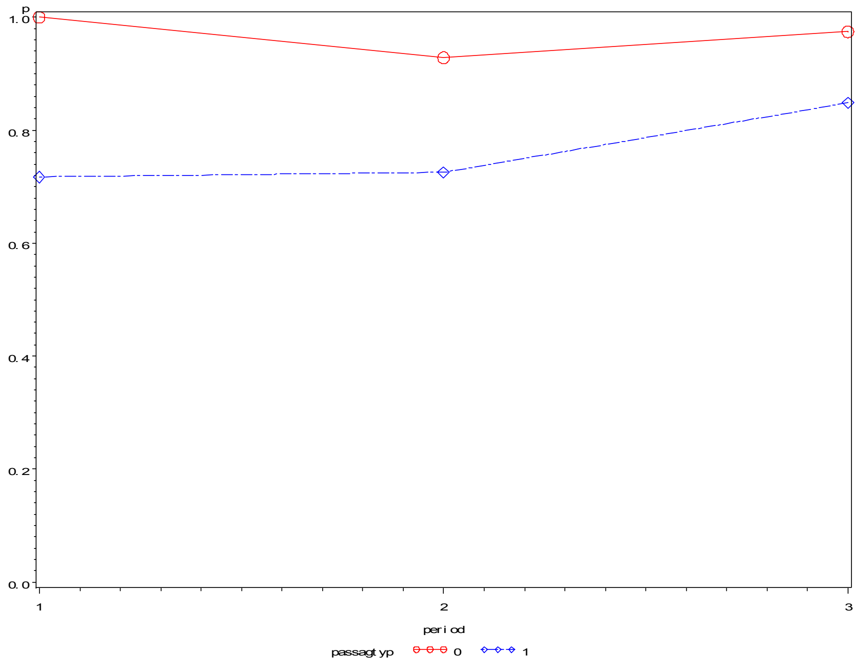
LR Statistics For Type 3 Analysis

Source	DF	Chi-Square	Pr > ChiSq
day	1	0.11	0.7445
dam	1	0.90	0.3438
flow	1	0.88	0.3483
flow*dam	1	0.54	0.4621



Appendix 2.B.7. 2002 Steelhead: Survival to Stella (BRG vs. ROR)

Obs	period	passagtyp	day	flow	y	n
1	1	1	5	6.96	33	46
2	1	0	5	6.96	16	16
3	2	1	15	6.61	37	51
4	2	0	15	6.60	13	14
5	3	1	28	8.78	84	99
6	3	0	28	8.78	38	39



Where 1 (diamond) = BRG and 0 (circle) = ROR

Model Information

Data Set	WORK.SURVIVAL2
Distribution	Binomial
Link Function	Logit
Response Variable (Events)	y
Response Variable (Trials)	n

Number of Observations Read	6
Number of Observations Used	6
Number of Events	221
Number of Trials	265

Class Level Information

Class	Levels	Values
period	3	1 2 3
passagtyp	2	0 1

Criteria For Assessing Goodness Of Fit

Criterion	DF	Value	Value/DF
Deviance	3	1.6765	0.5588
Scaled Deviance	3	1.6765	0.5588
Pearson Chi-Square	3	1.1127	0.3709
Scaled Pearson X2	3	1.1127	0.3709
Log Likelihood		-108.5596	

Algorithm converged.

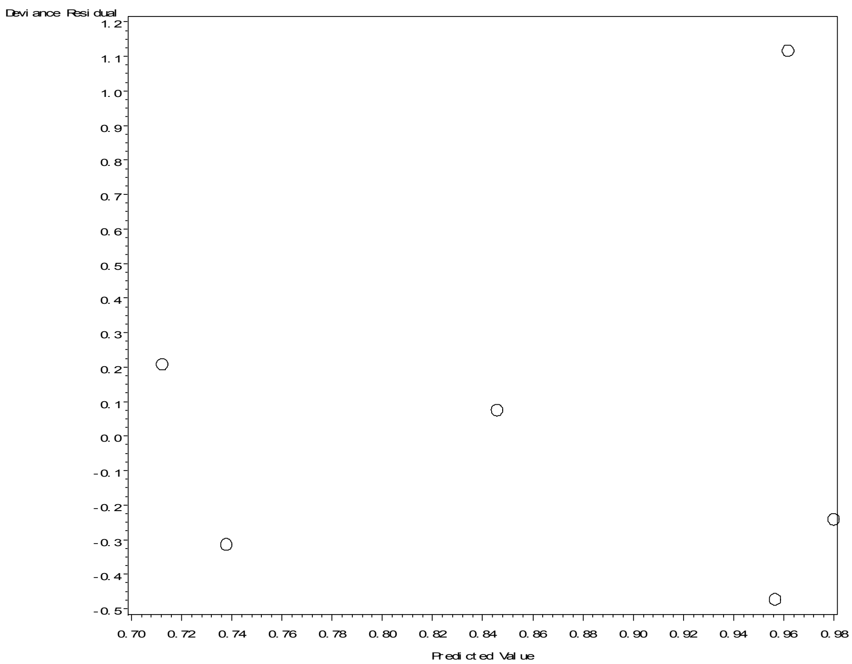
Analysis Of Parameter Estimates

Parameter		DF	Estimate	Standard Error	Wald 95% Confidence Limits		Chi-Square	Pr > ChiSq
Intercept		1	-1.5146	1.3160	-4.0939	1.0648	1.32	0.2498
passagtyp	0	1	2.1897	0.7402	0.7390	3.6405	8.75	0.0031
passagtyp	1	0	0.0000	0.0000	0.0000	0.0000	.	.
flow		1	0.3663	0.1722	0.0289	0.7037	4.53	0.0334

Scale	0	1.0000	0.0000	1.0000	1.0000

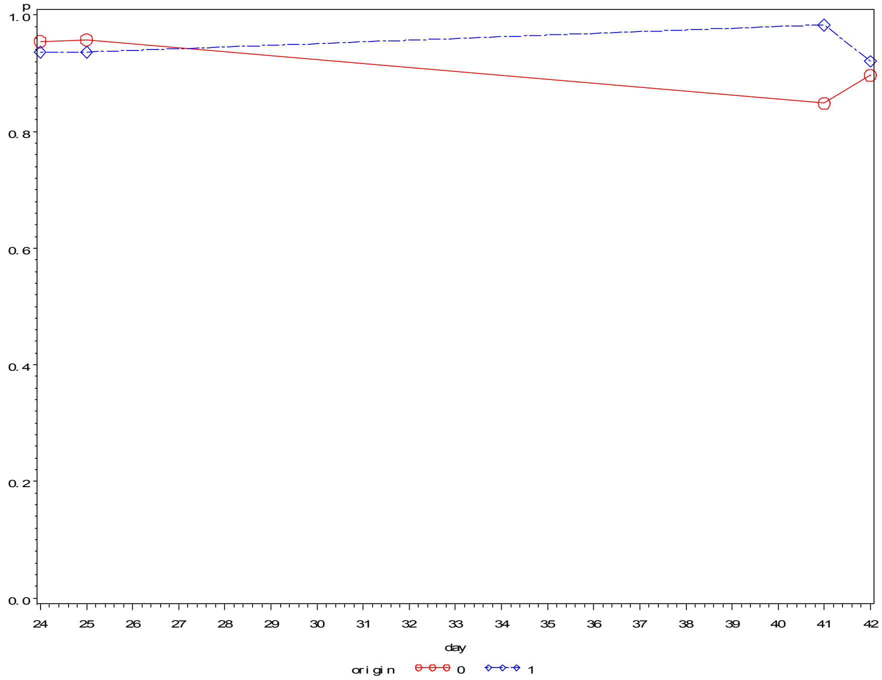
LR Statistics For Type 3 Analysis

Source	DF	Chi-Square	Pr > ChiSq
passagtyp	1	15.82	<.0001
flow	1	4.66	0.0308



Appendix 2.B.8. **2003 Steelhead: Survival to Stella (LGR hatchery vs. LGR wild)**

Obs	origin	day	flow	y	n
1	0	24	7.29	42	44
2	0	25	7.82	45	47
3	0	41	6.97	28	33
4	0	42	8.13	26	29
5	1	24	7.29	44	47
6	1	25	7.82	44	47
7	1	41	6.97	58	59
8	1	42	8.13	58	63



Where 1 (diamond) = hatchery and 0 (circle) = wild

Model Information

Data Set	WORK.SURVIVAL2
Distribution	Binomial
Link Function	Logit
Response Variable (Events)	y
Response Variable (Trials)	n

Number of Observations Read	8
Number of Observations Used	8
Number of Events	345
Number of Trials	369

Class Level Information

Class	Levels	Values
origin	2	0 1

Criteria For Assessing Goodness Of Fit

Criterion	DF	Value	Value/DF
Deviance	2	0.5517	0.2758
Scaled Deviance	2	0.5517	0.2758
Pearson Chi-Square	2	0.5559	0.2779
Scaled Pearson X2	2	0.5559	0.2779
Log Likelihood		-85.2108	

Algorithm converged.

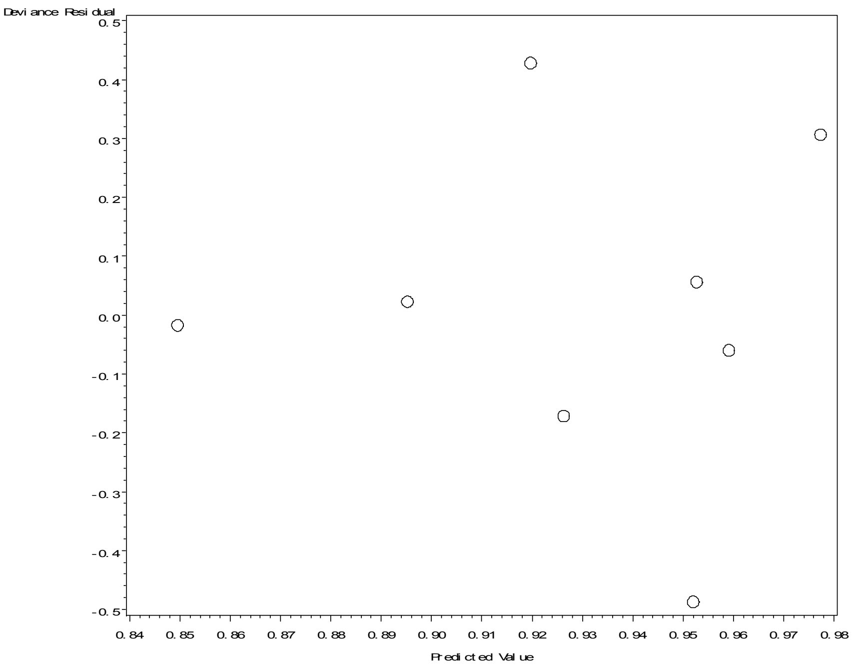
Analysis Of Parameter Estimates

Parameter		DF	Estimate	Standard Error	Wald 95% Confidence Limits		Chi-Square	Pr > ChiSq
Intercept		1	10.2962	5.7062	-0.8878	21.4801	3.26	0.0712
day		1	0.0253	0.0370	-0.0473	0.0978	0.47	0.4950
origin	0	1	-8.7081	7.5722	-23.5493	6.1331	1.32	0.2501
origin	1	0	0.0000	0.0000	0.0000	0.0000	.	.
flow		1	-1.0855	0.7755	-2.6054	0.4344	1.96	0.1616

flow*origin	0	1	1.5005	0.9991	-0.4578	3.4588	2.26	0.1332
flow*origin	1	0	0.0000	0.0000	0.0000	0.0000	.	.
day*origin	0	1	-0.0923	0.0528	-0.1958	0.0112	3.06	0.0805
day*origin	1	0	0.0000	0.0000	0.0000	0.0000	.	.
Scale		0	1.0000	0.0000	1.0000	1.0000		

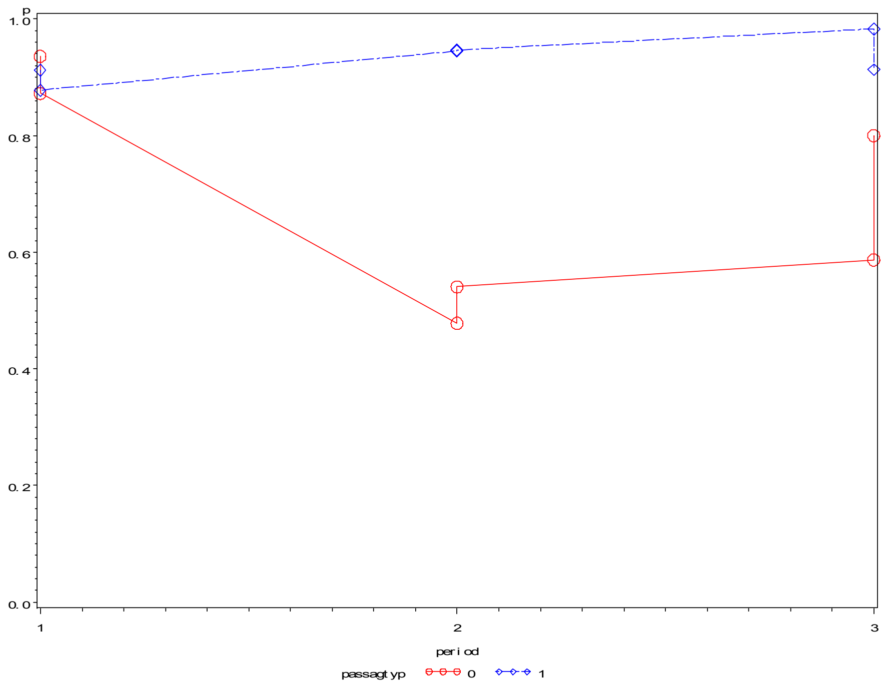
LR Statistics For Type 3 Analysis

Source	DF	Chi-Square	Pr > ChiSq
day	1	0.63	0.4273
origin	1	1.40	0.2365
flow	1	0.46	0.4956
flow*origin	1	2.46	0.1171
day*origin	1	3.15	0.0761



Appendix 2.B.9. 2003 Steelhead: Survival to Stella (BRG vs. ROR)

Obs	period	passagtyp	day	flow	y	n
1	1	1	3	6.23	83	91
2	1	0	3	6.25	44	47
3	1	1	4	6.35	79	90
4	1	0	4	6.35	41	47
5	2	1	24	7.29	86	91
6	2	0	24	7.29	22	46
7	2	1	25	7.82	89	94
8	2	0	25	7.82	20	37
9	3	1	41	6.97	58	59
10	3	0	41	7.01	27	46
11	3	1	42	8.13	84	92
12	3	0	42	8.13	36	45



Where 1 (diamond) = BRG and 0 (circle) = ROR

Model Information

Data Set	WORK.SURVIVAL2
Distribution	Binomial
Link Function	Logit
Response Variable (Events)	y
Response Variable (Trials)	n

Number of Observations Read	12
Number of Observations Used	12
Number of Events	669
Number of Trials	785

Class Level Information

Class	Levels	Values
period	3	1 2 3
passagtyp	2	0 1

Criteria For Assessing Goodness Of Fit

Criterion	DF	Value	Value/DF
Deviance	2	3.0289	1.5145
Scaled Deviance	2	2.0000	1.0000
Pearson Chi-Square	2	2.9604	1.4802
Scaled Pearson X2	2	1.9548	0.9774
Log Likelihood		-180.4924	

Algorithm converged.

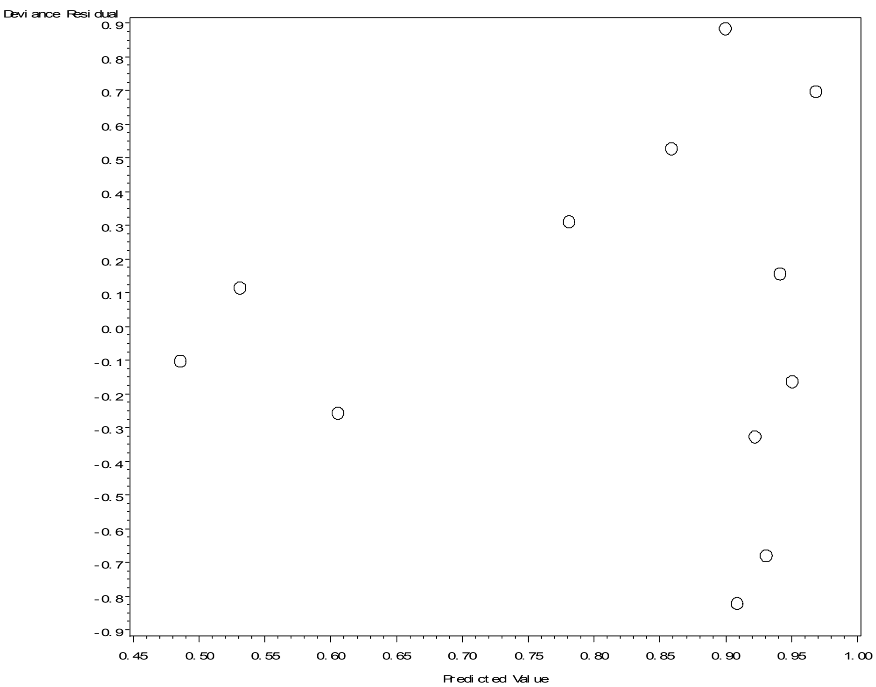
Analysis Of Parameter Estimates

Parameter		DF	Estimate	Standard Error	Wald 95% Confidence Limits		Chi-Square	Pr > ChiSq
Intercept		1	-1780.21	1019.873	-3779.12	218.7072	3.05	0.0809
period	1	1	2048.789	1172.742	-249.744	4347.322	3.05	0.0806
period	2	1	1534.788	879.1510	-188.316	3257.892	3.05	0.0809
period	3	0	0.0000	0.0000	0.0000	0.0000	.	.

day		1	51.1373	29.2981	-6.2859	108.5604	3.05	0.0809
day*period	1	1	-46.5436	26.3716	-98.2310	5.1438	3.11	0.0776
day*period	2	1	-27.1558	15.5629	-57.6586	3.3470	3.04	0.0810
day*period	3	0	0.0000	0.0000	0.0000	0.0000	.	.
passagtyp	0	1	-1.2030	0.6294	-2.4366	0.0306	3.65	0.0560

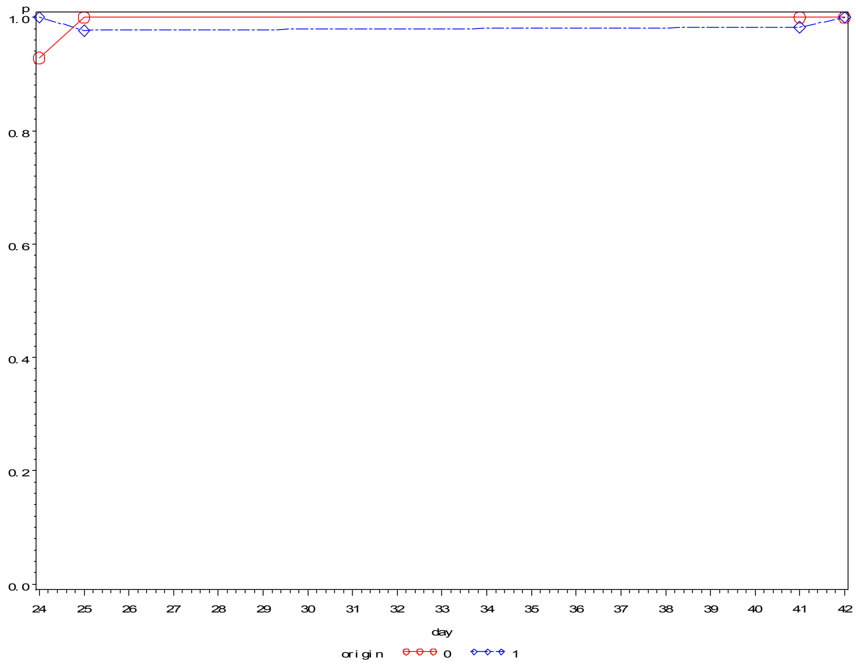
LR Statistics For Type 3 Analysis

Source	Num DF	Den DF	F Value	Pr > F	Chi-Square	Pr > ChiSq
period	2	2	1.74	0.3644	3.49	0.1747
day	1	2	3.37	0.2077	3.37	0.0663
day*period	2	2	1.92	0.3430	3.83	0.1473
passagtyp	1	2	10.61	0.0827	10.61	0.0011
flow	1	2	3.37	0.2078	3.37	0.0664
period*passagtyp	2	2	11.00	0.0833	22.00	<.0001



Appendix 2.B.10. **2003 Steelhead: Survival to Jim Crow Point (LGR hatchery vs. LGR wild)**

Obs	origin	day	flow	y	n
1	0	24	7.29	39	42
2	1	24	7.29	44	44
3	0	25	7.82	45	45
4	1	25	7.82	43	44
5	0	41	6.97	28	28
6	1	41	6.97	57	58
7	0	42	8.13	26	26
8	1	42	8.13	58	58



Where 1 (diamond) = hatchery and 0 (circle) = wild

Model Information

Data Set	WORK.SURVIVAL2
Distribution	Binomial
Link Function	Logit
Response Variable (Events)	y
Response Variable (Trials)	n

Number of Observations Read	8
Number of Observations Used	8
Number of Events	340
Number of Trials	345

Class Level Information

Class	Levels	Values
origin	2	0 1

Criteria For Assessing Goodness Of Fit

Criterion	DF	Value	Value/DF
Deviance	4	2.7929	0.6982
Scaled Deviance	4	2.7929	0.6982
Pearson Chi-Square	4	2.0205	0.5051
Scaled Pearson X2	4	2.0205	0.5051
Log Likelihood		-22.0284	

WARNING: Negative of Hessian not positive definite.

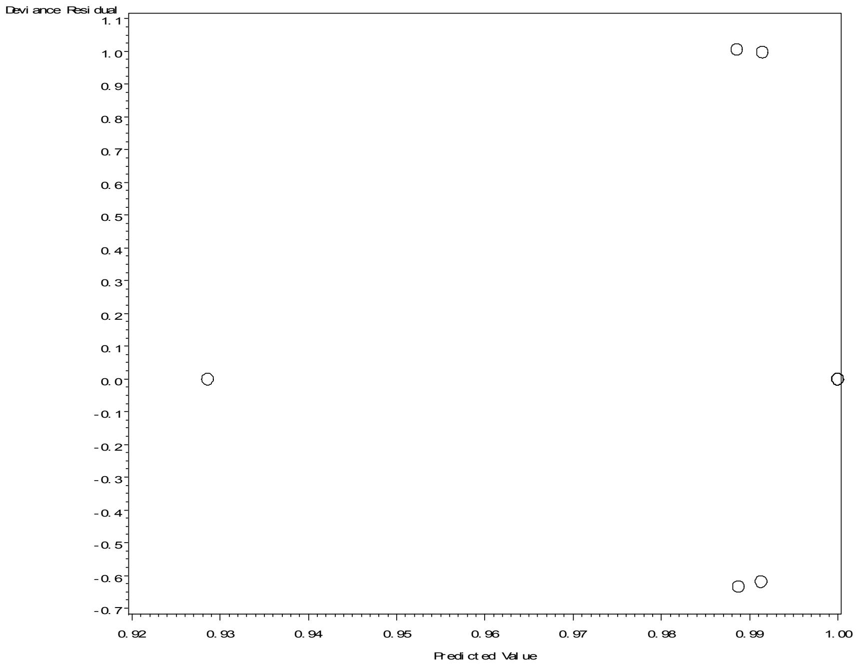
Analysis Of Parameter Estimates

Parameter		DF	Estimate	Standard Error	Wald 95% Confidence Limits		Chi-Square	Pr > ChiSq
Intercept		1	4.0657	2.8455	-1.5113	9.6427	2.04	0.1531
origin	0	1	-540.551	1.1957	-542.895	-538.208	204367	<.0001
origin	1	0	0.0000	0.0000	0.0000	0.0000	.	.
day		1	0.0164	0.0835	-0.1472	0.1799	0.04	0.8446
day*origin	0	0	22.4441	0.0000	22.4441	22.4441	.	.
day*origin	1	0	0.0000	0.0000	0.0000	0.0000	.	.

Scale	0	1.0000	0.0000	1.0000	1.0000

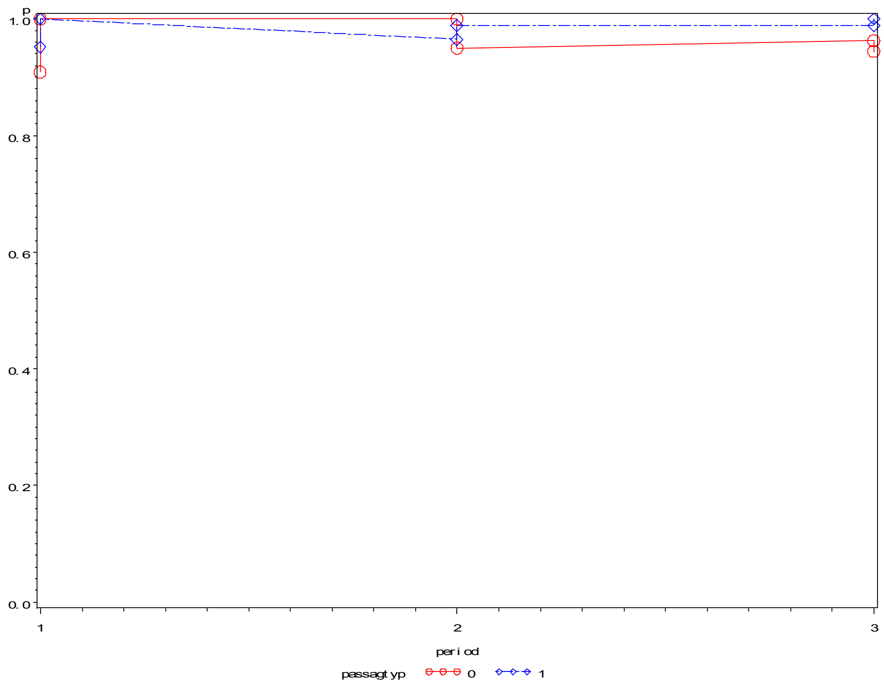
LR Statistics For Type 1 Analysis

Source	Deviance	DF	Chi-Square	Pr > ChiSq
Intercept	11.0045			
origin	10.2530	1	0.75	0.3860
day	8.5026	1	1.75	0.1858
day*origin	2.7929	1	5.71	0.0169



Appendix 2.B.11. **2003 Steelhead: Survival to Jim Crow Point (BRG vs. ROR)**

Obs	period	passagtyp	day	flow	y	n
1	1	1	3	6.23	79	83
2	1	0	3	6.25	40	44
3	1	1	4	6.35	79	79
4	1	0	4	6.35	41	41
5	2	1	24	7.29	83	86
6	2	0	24	7.29	22	22
7	2	1	25	7.82	88	89
8	2	0	25	7.82	19	20
9	3	1	41	6.97	85	86
10	3	0	41	7.01	26	27
11	3	1	42	8.13	84	84
12	3	0	42	8.13	34	36



Where 1 (diamond) = BRG and 0 (circle) = ROR

Model Information

Data Set	WORK.SURVIVAL2
Distribution	Binomial
Link Function	Logit
Response Variable (Events)	y
Response Variable (Trials)	n

Number of Observations Read	12
Number of Observations Used	12
Number of Events	680
Number of Trials	697

Class Level Information

Class	Levels	Values
period	3	1 2 3
passagtyp	2	0 1

Criteria For Assessing Goodness Of Fit

Criterion	DF	Value	Value/DF
Deviance	5	5.9904	1.1981
Scaled Deviance	5	5.0000	1.0000
Pearson Chi-Square	5	4.2166	0.8433
Scaled Pearson X2	5	3.5195	0.7039
Log Likelihood		-60.3876	

Algorithm converged.

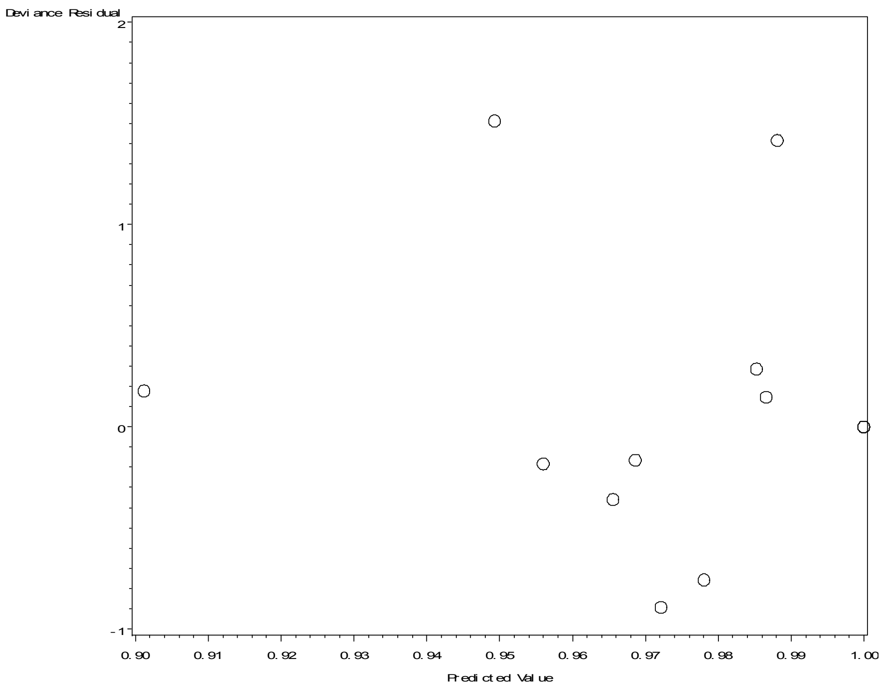
Analysis Of Parameter Estimates

Parameter		DF	Estimate	Standard Error	Wald 95% Confidence Limits		Chi-Square	Pr > ChiSq
Intercept		1	-0.7362	45.9254	-90.7484	89.2760	0.00	0.9872
period	1	1	-70.2806	42.6180	-153.810	13.2492	2.72	0.0991
period	2	1	-5.1654	52.1701	-107.417	97.0861	0.01	0.9211
period	3	0	0.0000	0.0000	0.0000	0.0000	.	.
day		1	0.1228	1.1068	-2.0464	2.2920	0.01	0.9117

day*period	1	0	24.5756	0.0000	24.5756	24.5756	.	.
day*period	2	1	0.2814	1.5005	-2.6595	3.2222	0.04	0.8513
day*period	3	0	0.0000	0.0000	0.0000	0.0000	.	.
passagtyp	0	1	-0.8680	0.5525	-1.9510	0.2149	2.47	0.1162

LR Statistics For Type 3 Analysis

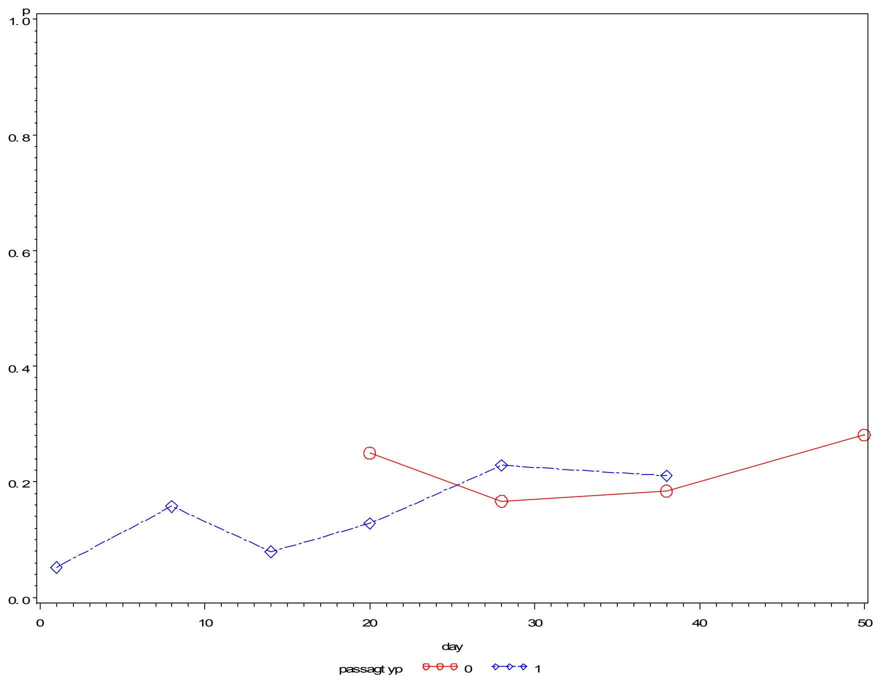
Source	Num DF	Den DF	F Value	Pr > F	Chi-Square	Pr > ChiSq
period	2	5	0.10	0.9029	0.21	0.9010
day	1	5	4.40	0.0900	4.40	0.0359
day*period	2	5	2.50	0.1771	4.99	0.0824
passagtyp	1	5	2.37	0.1842	2.37	0.1235



Mortality Analyses: Logistic Regression Output

Appendix 2.C.1. **1996 spring/summer Chinook Mortality: Barged vs. ROR**

Obs	passagtyp	day	y	n
1	1	1	2	38
2	1	8	6	38
3	1	14	3	38
4	0	20	8	32
5	1	20	5	39
6	0	28	2	12
7	1	28	8	35
8	0	38	7	38
9	1	38	8	38
10	0	50	9	32
11	1	50	0	0



Where 1 (diamond) = barged and 0 (circle) = ROR

Model Information

Data Set	WORK.SURVIVAL2
Distribution	Binomial
Link Function	Logit
Response Variable (Events)	y
Response Variable (Trials)	n

Number of Observations Read	11
Number of Observations Used	10
Number of Events	58
Number of Trials	340
Number of Invalid Responses	1

Class Level Information

Class	Levels	Values
passagtyp	2	0 1

Criteria For Assessing Goodness Of Fit

Criterion	DF	Value	Value/DF
Deviance	6	4.2900	0.7150
Scaled Deviance	6	4.2900	0.7150
Pearson Chi-Square	6	4.3870	0.7312
Scaled Pearson X2	6	4.3870	0.7312
Log Likelihood		-150.9230	

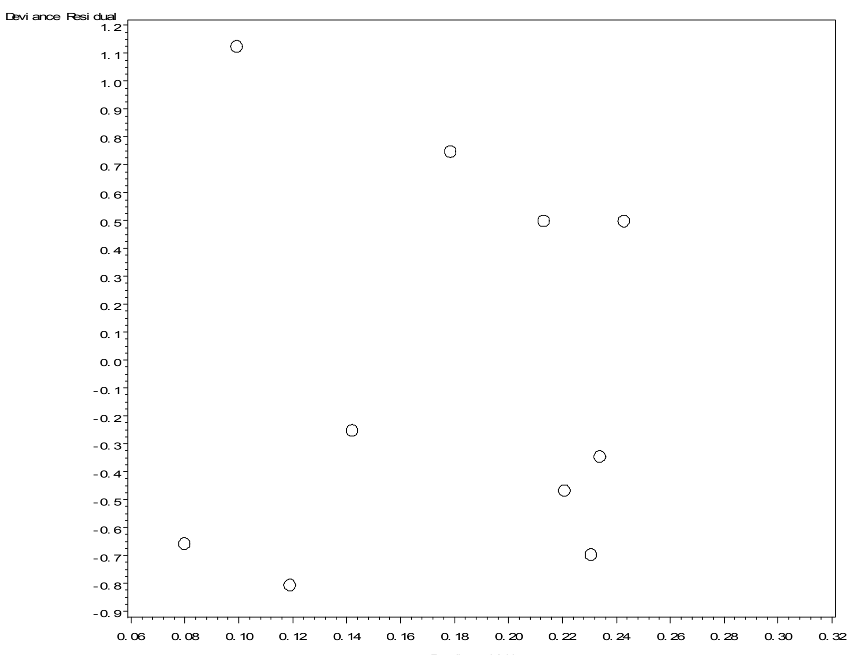
Algorithm converged.

Analysis Of Parameter Estimates

Parameter		DF	Estimate	Standard Error	Wald 95% Confidence Limits		Chi-Square	Pr > ChiSq
Intercept		1	-2.4785	0.3902	-3.2434	-1.7136	40.34	<.0001
day		1	0.0340	0.0156	0.0034	0.0646	4.74	0.0295
passagtyp	0	1	1.0595	0.8224	-0.5524	2.6714	1.66	0.1977
passagtyp	1	0	0.0000	0.0000	0.0000	0.0000	.	.
day*passagtyp	0	1	-0.0284	0.0248	-0.0770	0.0203	1.31	0.2532
day*passagtyp	1	0	0.0000	0.0000	0.0000	0.0000	.	.
Scale		0	1.0000	0.0000	1.0000	1.0000		

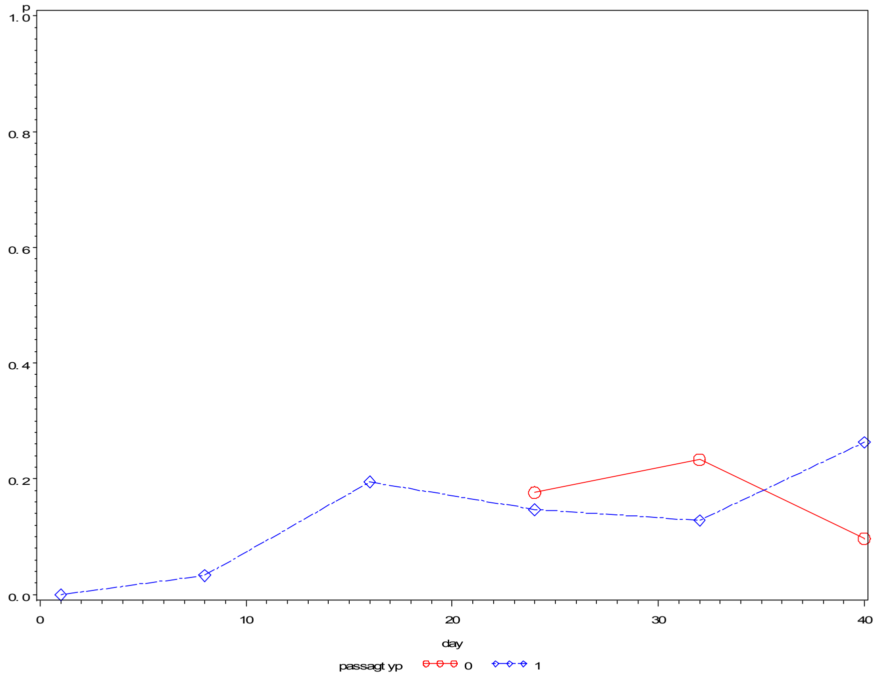
LR Statistics For Type 3 Analysis

Source	DF	Chi-Square	Pr > ChiSq
day	1	2.57	0.1091
passagtyp	1	1.61	0.2052
day*passagtyp	1	1.30	0.2538



Appendix 2.C.2. **1997 spring/summer Chinook Mortality: Barged vs. ROR**

Obs	passagtyp	day	y	n
1	1	1	0	30
2	1	8	1	30
3	1	16	7	36
4	0	24	6	34
5	1	24	5	34
6	0	32	7	30
7	1	32	5	39
8	0	40	3	31
9	1	40	10	38



Where 1 (diamond)= barged and 0 (circle) = ROR

Model Information

Data Set	WORK.SURVIVAL2
Distribution	Binomial
Link Function	Logit
Response Variable (Events)	y
Response Variable (Trials)	n

Number of Observations Read	9
Number of Observations Used	9
Number of Events	44
Number of Trials	302

Class Level Information

Class	Levels	Values
passagtyp	2	0 1

Criteria For Assessing Goodness Of Fit

Criterion	DF	Value	Value/DF
Deviance	5	9.3180	1.8636
Scaled Deviance	5	5.0000	1.0000
Pearson Chi-Square	5	8.9167	1.7833
Scaled Pearson X2	5	4.7847	0.9569
Log Likelihood		-64.2893	

Algorithm converged.

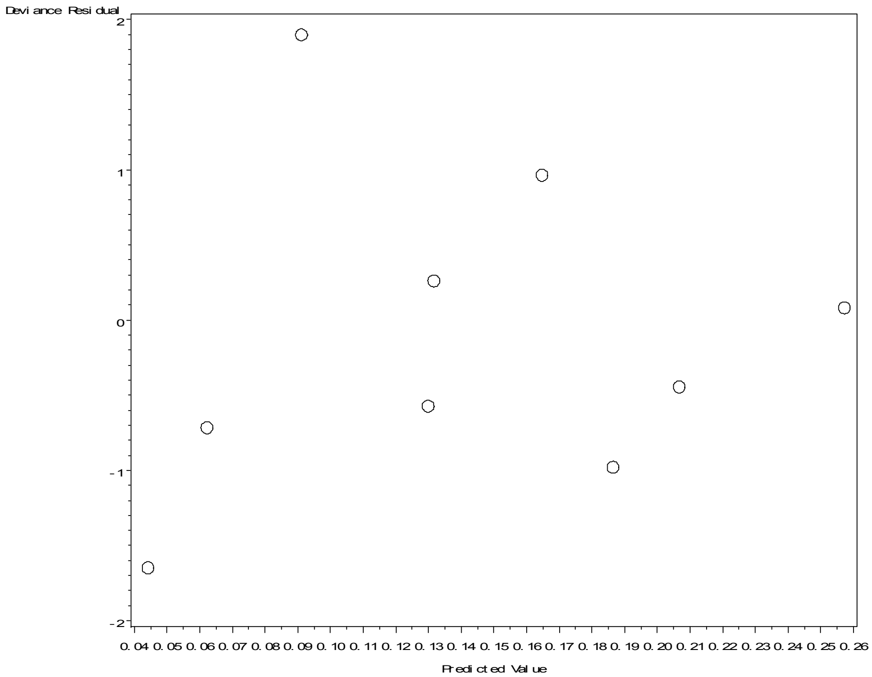
Analysis Of Parameter Estimates

Parameter		DF	Estimate	Standard Error	Wald 95% Confidence Limits		Chi-Square	Pr > ChiSq
Intercept		1	-3.1258	0.7188	-4.5346	-1.7171	18.91	<.0001
day		1	0.0516	0.0239	0.0047	0.0986	4.65	0.0310
passagtyp	0	1	2.6159	1.9497	-1.2055	6.4373	1.80	0.1797
passagtyp	1	0	0.0000	0.0000	0.0000	0.0000	.	.

day*passagtyp	0	1	-0.0864	0.0624	-0.2088	0.0359	1.92	0.1663
day*passagtyp	1	0	0.0000	0.0000	0.0000	0.0000	.	.
Scale		0	1.3651	0.0000	1.3651	1.3651		

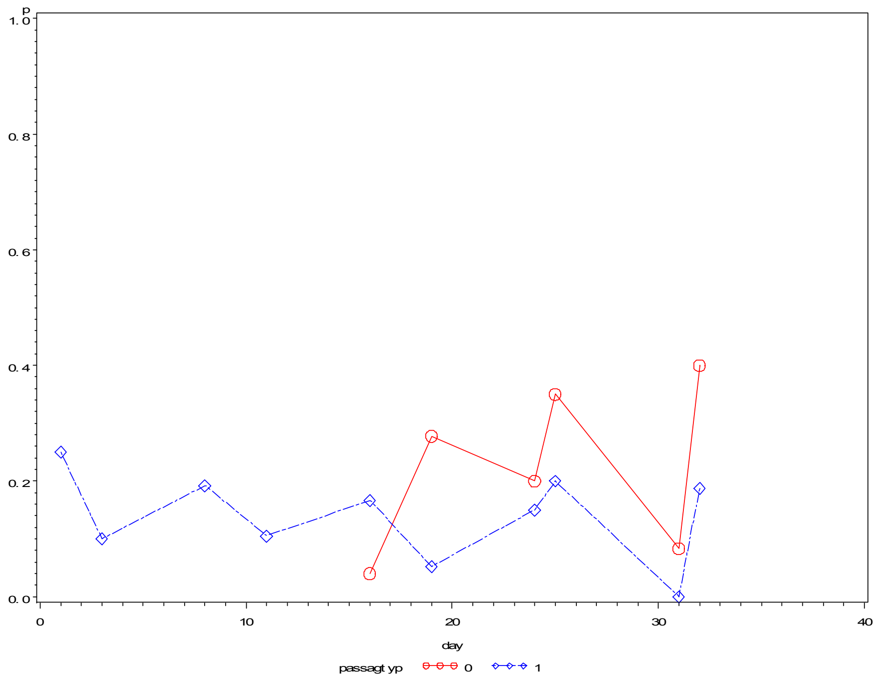
LR Statistics For Type 3 Analysis

Source	Num DF	Den DF	F Value	Pr > F	Chi-Square	Pr > ChiSq
day	1	5	0.07	0.7987	0.07	0.7879
passagtyp	1	5	1.76	0.2425	1.76	0.1852
day*passagtyp	1	5	1.97	0.2195	1.97	0.1606



Appendix 2.C.3. 1998 spring/summer Chinook Mortality: Barged vs. ROR

Obs	passagtyp	day	y	n
1	1	1	6	24
2	1	3	2	20
3	1	8	5	26
4	1	11	2	19
5	0	16	1	25
6	1	16	4	24
7	0	19	5	18
8	1	19	1	19
9	0	24	5	25
10	1	24	3	20
11	0	25	7	20
12	1	25	5	25
13	0	31	2	24
14	1	31	0	14
15	0	32	6	15
16	1	32	3	16



Where 1 (diamond) = barged and 0 (ROR) = ROR

Model Information

Data Set	WORK.SURVIVAL2
Distribution	Binomial
Link Function	Logit
Response Variable (Events)	y
Response Variable (Trials)	n

Number of Observations Read	16
Number of Observations Used	16
Number of Events	57
Number of Trials	334

Class Level Information

Class	Levels	Values
passagtyp	2	0 1

Criteria For Assessing Goodness Of Fit

Criterion	DF	Value	Value/DF
Deviance	14	23.9600	1.7114
Scaled Deviance	14	14.0000	1.0000
Pearson Chi-Square	14	20.5879	1.4706
Scaled Pearson X2	14	12.0296	0.8593
Log Likelihood		-88.6908	

Algorithm converged.

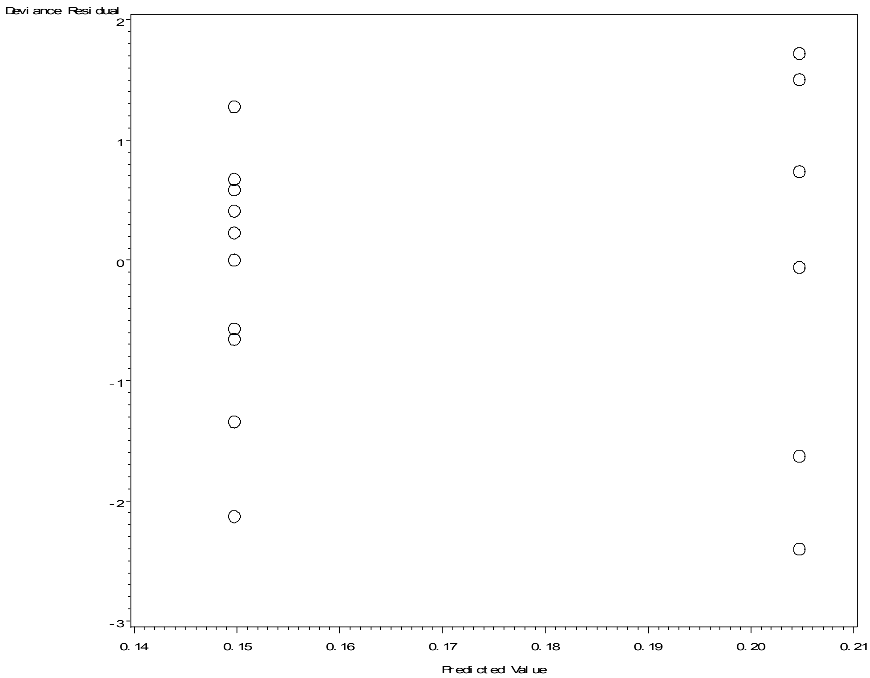
Analysis Of Parameter Estimates

Parameter		DF	Estimate	Standard Error	Wald 95% Confidence Limits		Chi-Square	Pr > ChiSq
Intercept		1	-1.7365	0.2548	-2.2359	-1.2371	46.44	<.0001
passagtyp	0	1	0.3795	0.3843	-0.3738	1.1327	0.97	0.3235
passagtyp	1	0	0.0000	0.0000	0.0000	0.0000	.	.

Scale	0	1.3082	0.0000	1.3082	1.3082

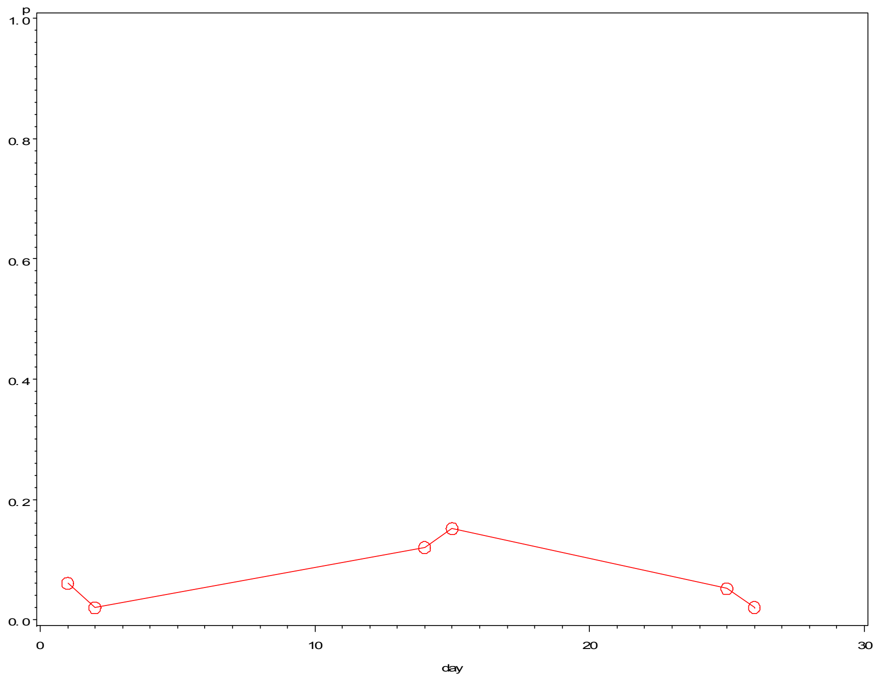
LR Statistics For Type 3 Analysis

Source	Num DF	Den DF	F Value	Pr > F	Chi-Square	Pr > ChiSq
passagtyp	1	14	0.97	0.3425	0.97	0.3258



Appendix 2.C.4. 2004 Barged spring/summer Chinook Mortality

Obs	period	day	y	n
1	1	1	6	99
2	1	2	2	101
3	2	14	12	100
4	2	15	15	99
5	3	25	5	97
6	3	26	2	98



Model Information

Data Set	WORK.SURVIVAL2
Distribution	Binomial
Link Function	Logit
Response Variable (Events)	y
Response Variable (Trials)	n

Number of Observations Read	6
Number of Observations Used	6
Number of Events	42
Number of Trials	594

Class Level Information

Class	Levels	Values
period	3	1 2 3

Criteria For Assessing Goodness Of Fit

Criterion	DF	Value	Value/DF
Deviance	3	4.0908	1.3636
Scaled Deviance	3	3.0000	1.0000
Pearson Chi-Square	3	3.9548	1.3183
Scaled Pearson X2	3	2.9002	0.9667
Log Likelihood		-104.6946	

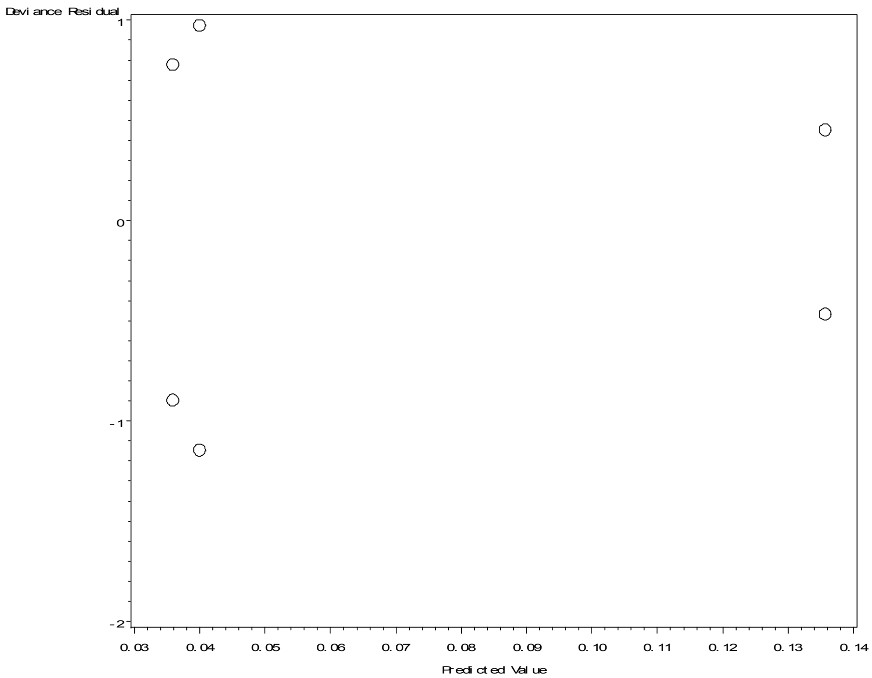
Algorithm converged.

Analysis Of Parameter Estimates

Parameter		DF	Estimate	Standard Error	Wald 95% Confidence Limits		Chi-Square	Pr > ChiSq
Intercept		1	-3.2905	0.4495	-4.1715	-2.4095	53.59	<.0001
period	1	1	0.1125	0.6161	-1.0951	1.3201	0.03	0.8551
period	2	1	1.4389	0.5104	0.4386	2.4392	7.95	0.0048
period	3	0	0.0000	0.0000	0.0000	0.0000	.	.
Scale		0	1.1677	0.0000	1.1677	1.1677		

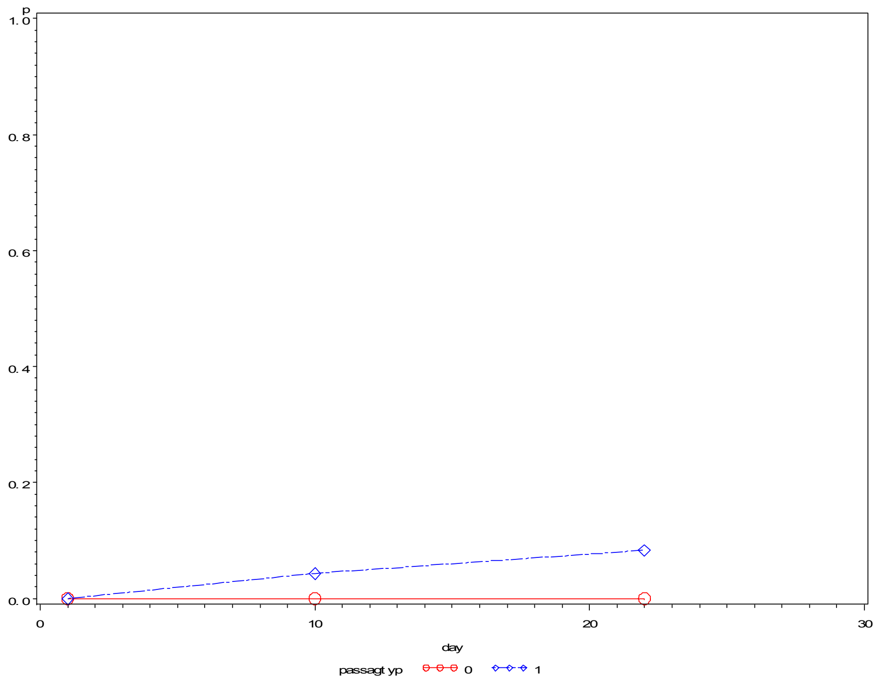
LR Statistics For Type 3 Analysis

Source	Num DF	Den DF	F Value	Pr > F	Chi-Square	Pr > ChiSq
period	2	3	6.59	0.0799	13.18	0.0014



Appendix 2.C.5. **2001 fall Chinook Mortality: Barged vs. ROR**

Obs	period	passagtyp	day	y	n
1	1	0	1	0	21
2	1	1	1	0	10
3	2	0	10	0	20
4	2	1	10	1	23
5	3	0	22	0	32
6	3	1	22	2	24



Where 1 (diamond) = barged and 0 (circle) = ROR

Model Information

Data Set	WORK.GB2
Distribution	Binomial
Link Function	Logit
Response Variable (Events)	y
Response Variable (Trials)	n

Number of Observations Read	6
Number of Observations Used	6
Number of Events	3
Number of Trials	130

Class Level Information

Class	Levels	Values
period	3	1 2 3
passagtyp	2	0 1

Criteria For Assessing Goodness Of Fit

Criterion	DF	Value	Value/DF
Deviance	3	0.3886	0.1295
Scaled Deviance	3	0.3886	0.1295
Pearson Chi-Square	3	0.2497	0.0832
Scaled Pearson X2	3	0.2497	0.0832
Log Likelihood		-11.1918	

Algorithm converged.

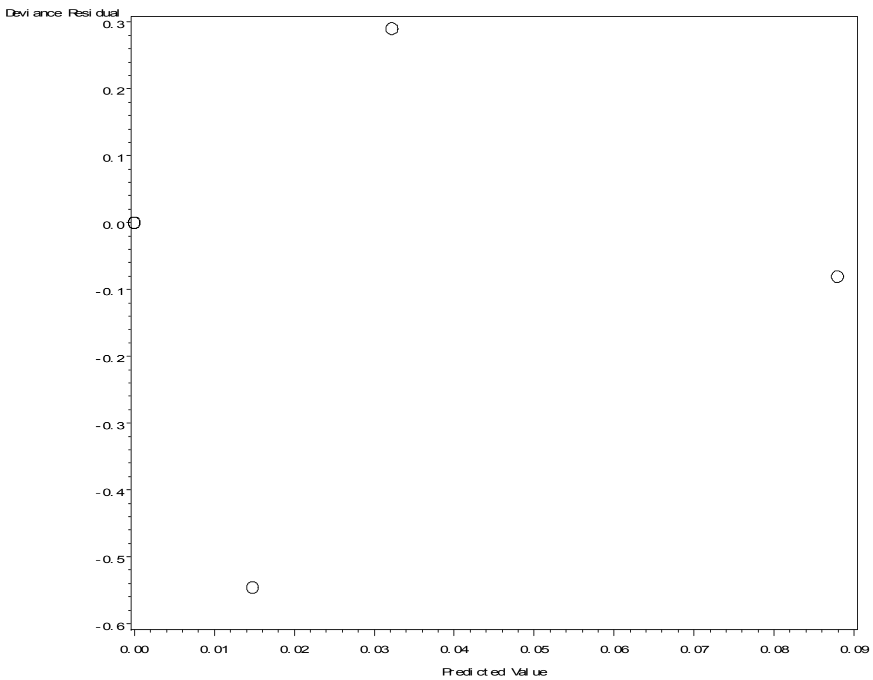
Analysis Of Parameter Estimates

Parameter		DF	Estimate	Standard Error	Wald 95% Confidence Limits		Chi-Square	Pr > ChiSq
Intercept		1	-4.2880	1.7413	-7.7010	-0.8751	6.06	0.0138
day		1	0.0886	0.0918	-0.0913	0.2685	0.93	0.3344
passagtyp	0	1	-26.3575	262306.8	-514138	514085.5	0.00	0.9999
passagtyp	1	0	0.0000	0.0000	0.0000	0.0000	.	.

Scale	0	1.0000	0.0000	1.0000	1.0000

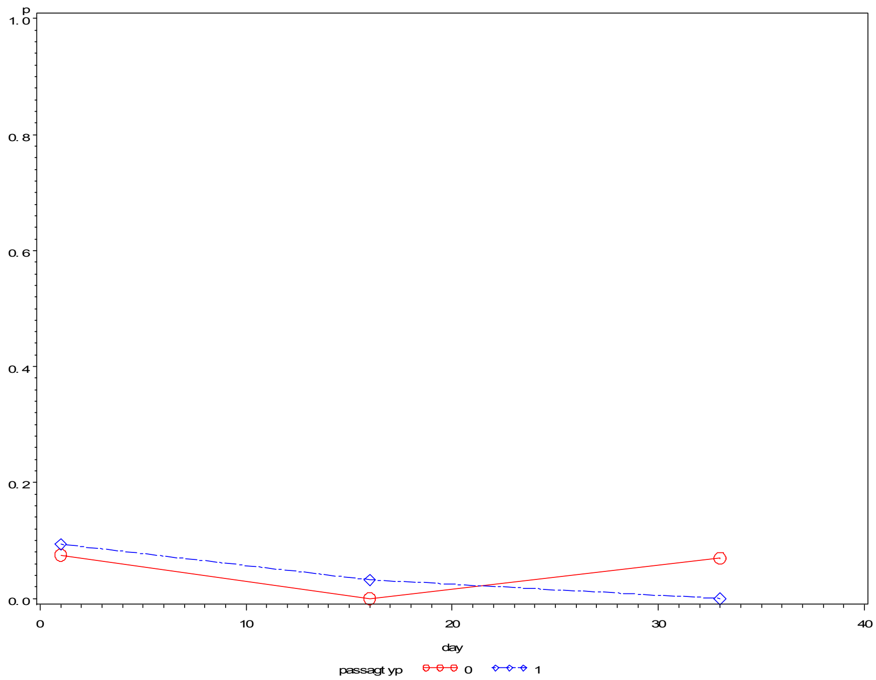
LR Statistics For Type 3 Analysis

Source	DF	Chi-Square	Pr > ChiSq
day	1	1.12	0.2894
passagtyp	1	5.01	0.0252



Appendix 2.C.6. **2002 fall Chinook Mortality: Barged vs. ROR**

Obs	period	passagtyp	day	y	n
1	1	0	1	3	40
2	1	1	1	3	32
3	2	0	16	0	40
4	2	1	16	1	31
5	3	0	33	3	43
6	3	1	33	0	41



Where 1 (diamond) = barged and 0 (circle) = ROR

Model Information

Data Set	WORK.GB2
Distribution	Binomial
Link Function	Logit
Response Variable (Events)	y
Response Variable (Trials)	n

Number of Observations Read	6
Number of Observations Used	6
Number of Events	10
Number of Trials	227

Class Level Information

Class	Levels	Values
period	3	1 2 3
passagtyp	2	0 1

Criteria For Assessing Goodness Of Fit

Criterion	DF	Value	Value/DF
Deviance	3	8.2808	2.7603
Scaled Deviance	3	3.0000	1.0000
Pearson Chi-Square	3	6.5130	2.1710
Scaled Pearson X2	3	2.3595	0.7865
Log Likelihood		-14.5095	

Algorithm converged.

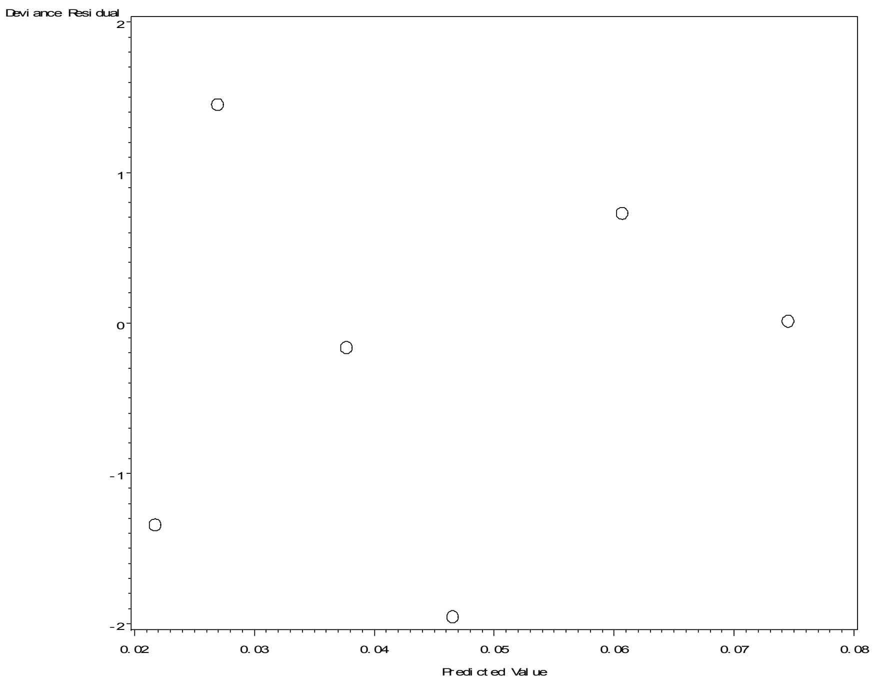
Analysis Of Parameter Estimates

Parameter	DF	Estimate	Standard Error	Wald 95% Confidence Limits		Chi-Square	Pr > ChiSq
Intercept	1	-2.7064	1.0121	-4.6901	-0.7227	7.15	0.0075
day	1	-0.0334	0.0432	-0.1180	0.0513	0.60	0.4397

passagtyp	0	1	0.2204	1.1006	-1.9367	2.3774	0.04	0.8413
passagtyp	1	0	0.0000	0.0000	0.0000	0.0000	.	.
Scale		0	1.6614	0.0000	1.6614	1.6614		

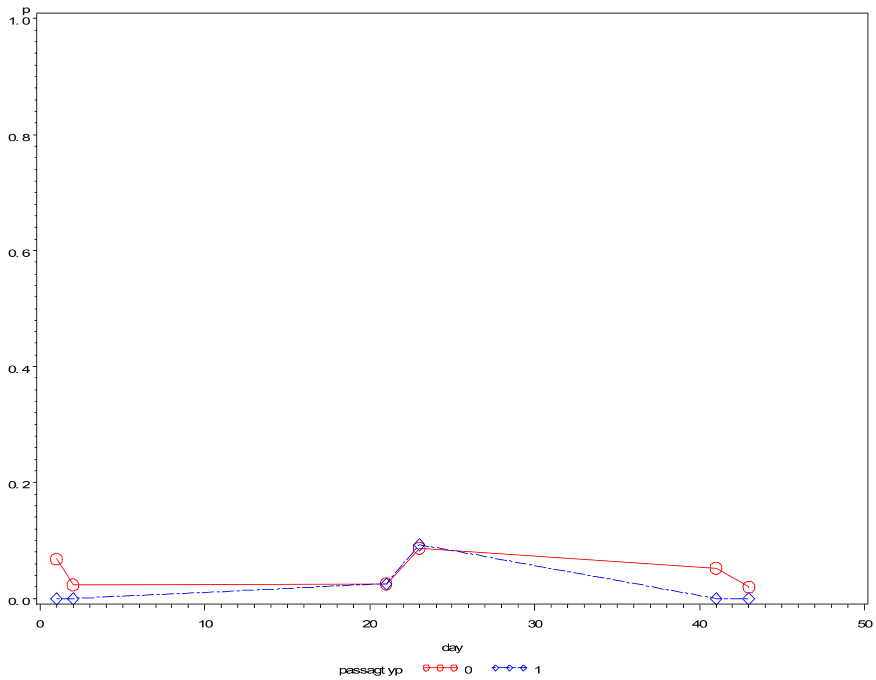
LR Statistics For Type 3 Analysis

Source	Num DF	Den DF	F Value	Pr > F	Chi-Square	Pr > ChiSq
day	1	3	0.64	0.4834	0.64	0.4251
passagtyp	1	3	0.04	0.8533	0.04	0.8404



Appendix 2.C.7. 2003 fall Chinook Mortality: Barged vs. ROR

Obs	period	passagtyp	day	y	n
1	1	0	1	3	44
2	1	1	1	0	31
3	1	0	2	1	42
4	1	1	2	0	59
5	2	0	21	1	39
6	2	1	21	1	39
7	2	0	23	4	46
8	2	1	23	4	43
9	3	0	41	2	38
10	3	1	41	0	46
11	3	0	43	1	50
12	3	1	43	0	41



Where 1 (diamond) = barged and 0 (circle) = ROR

Model Information

Data Set	WORK.GB2
Distribution	Binomial
Link Function	Logit
Response Variable (Events)	y
Response Variable (Trials)	n

Number of Observations Read	12
Number of Observations Used	12
Number of Events	17
Number of Trials	518

Class Level Information

Class	Levels	Values
period	3	1 2 3
passagtyp	2	0 1

Criteria For Assessing Goodness Of Fit

Criterion	DF	Value	Value/DF
Deviance	5	6.7867	1.3573
Scaled Deviance	5	5.0000	1.0000
Pearson Chi-Square	5	5.0480	1.0096
Scaled Pearson X2	5	3.7191	0.7438
Log Likelihood		-50.1035	

Algorithm converged.

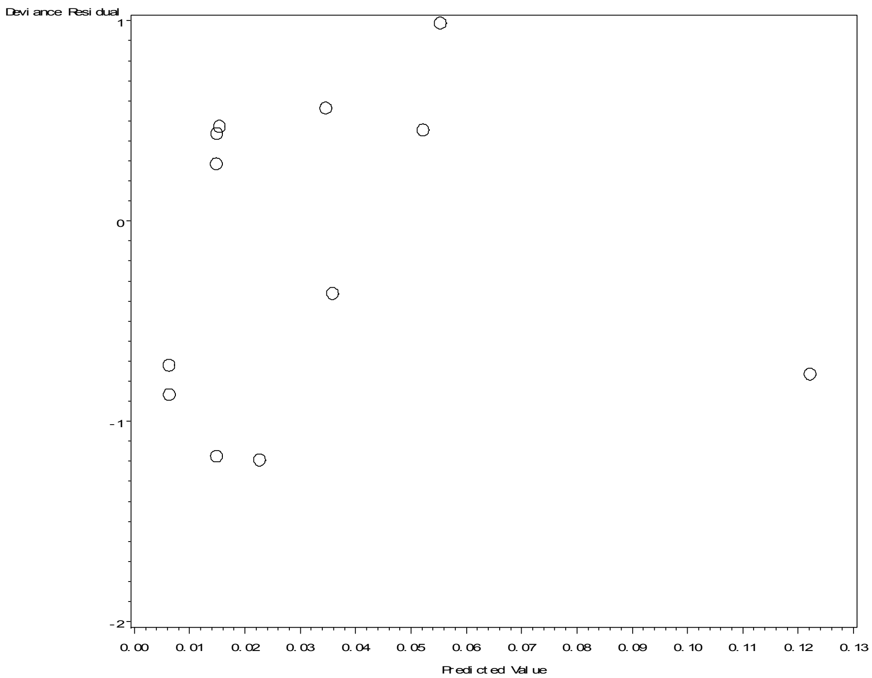
Analysis Of Parameter Estimates

Parameter		DF	Estimate	Standard Error	Wald 95% Confidence Limits		Chi-Square	Pr > ChiSq
Intercept		1	13.5991	30.0157	-45.2305	72.4287	0.21	0.6505
day		1	-0.4340	0.7204	-1.8459	0.9780	0.36	0.5469
period	1	1	-16.0714	30.0891	-75.0450	42.9022	0.29	0.5933

period	2	1	-31.6106	31.8628	-94.0605	30.8394	0.98	0.3212
period	3	0	0.0000	0.0000	0.0000	0.0000	.	.
day*period	1	1	-0.8577	1.5423	-3.8805	2.1651	0.31	0.5781
day*period	2	1	1.0937	0.8609	-0.5937	2.7811	1.61	0.2040
day*period	3	0	0.0000	0.0000	0.0000	0.0000	.	.
passagtyp	0	1	0.8652	0.6375	-0.3843	2.1146	1.84	0.1747

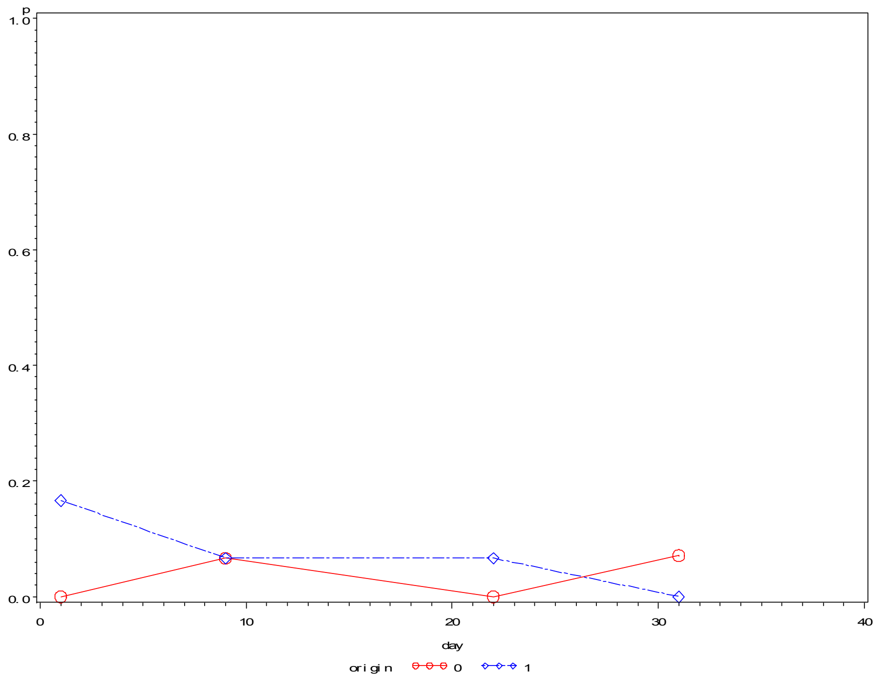
LR Statistics For Type 3 Analysis

Source	Num DF	Den DF	F Value	Pr > F	Chi-Square	Pr > ChiSq
day	1	5	0.47	0.5220	0.47	0.4914
period	2	5	1.45	0.3196	2.89	0.2356
day*period	2	5	1.68	0.2768	3.36	0.1865
passagtyp	1	5	2.00	0.2162	2.00	0.1570



Appendix 2.C.8. 2001 Steelhead Mortality: Barged Hatchery vs. Barged Wild

Obs	origin	day	y	n
1	0	1	0	10
2	1	1	3	18
3	0	9	1	15
4	1	9	1	15
5	0	22	0	15
6	1	22	1	15
7	0	31	1	14
8	1	31	0	22



Where 1 (diamond) = hatchery and 0 (circle) = wild

Model Information

Data Set	WORK.GB2
Distribution	Binomial
Link Function	Logit
Response Variable (Events)	y
Response Variable (Trials)	n

Number of Observations Read	8
Number of Observations Used	8
Number of Events	7
Number of Trials	124

Class Level Information

Class	Levels	Values
origin	2	0 1

Criteria For Assessing Goodness Of Fit

Criterion	DF	Value	Value/DF
Deviance	4	3.6102	0.9025
Scaled Deviance	4	3.6102	0.9025
Pearson Chi-Square	4	2.8507	0.7127
Scaled Pearson X2	4	2.8507	0.7127
Log Likelihood		-24.5395	

Algorithm converged.

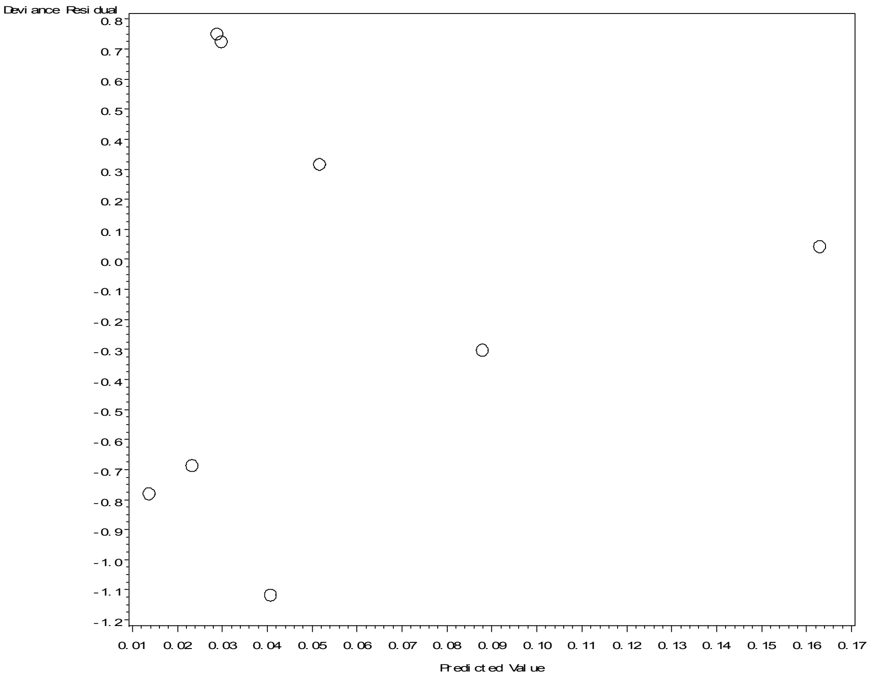
Analysis Of Parameter Estimates

Parameter		DF	Estimate	Standard Error	Wald 95% Confidence Limits		Chi-Square	Pr > ChiSq
Intercept		1	-1.5487	0.6125	-2.7493	-0.3482	6.39	0.0115
day		1	-0.0879	0.0526	-0.1909	0.0151	2.80	0.0944
origin	0	1	-2.2162	1.6457	-5.4418	1.0094	1.81	0.1781
origin	1	0	0.0000	0.0000	0.0000	0.0000	.	.
day*origin	0	1	0.1155	0.0857	-0.0525	0.2835	1.82	0.1778
day*origin	1	0	0.0000	0.0000	0.0000	0.0000	.	.

Scale	0	1.0000	0.0000	1.0000	1.0000

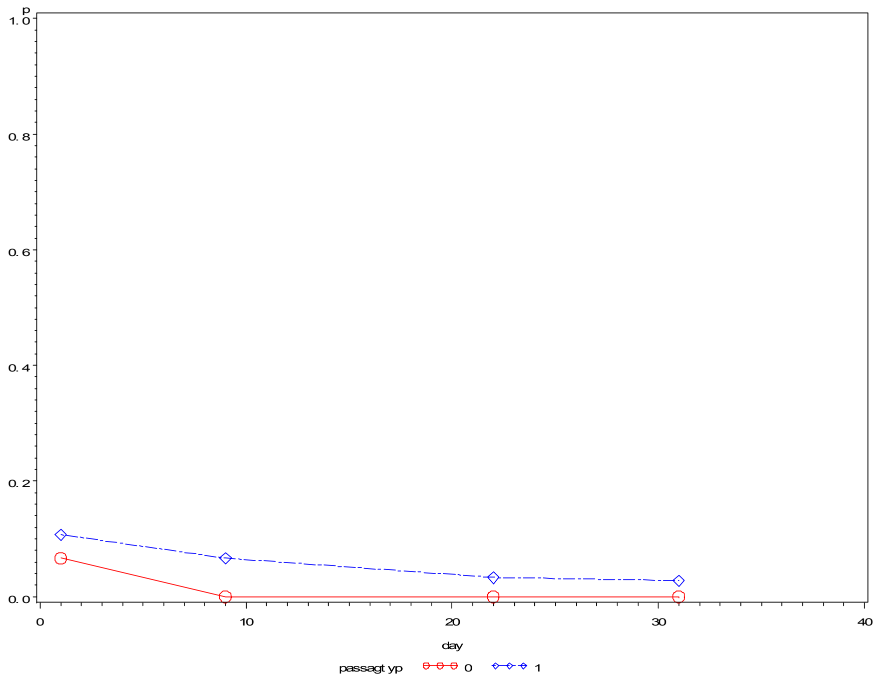
LR Statistics For Type 3 Analysis

Source	DF	Chi-Square	Pr > ChiSq
day	1	0.48	0.4870
origin	1	2.53	0.1116
day*origin	1	1.99	0.1579



Appendix 2.C.9. 2001 Steelhead Mortality: Barged vs. ROR

Obs	passagtyp	day	y	n
1	0	1	1	15
2	1	1	3	28
3	0	9	0	15
4	1	9	2	30
5	0	22	0	15
6	1	22	1	30
7	0	31	0	24
8	1	31	1	36



Where 1 (diamond) = barged and 0 (circle) = ROR

Model Information

Data Set	WORK.GB2
Distribution	Binomial
Link Function	Logit
Response Variable (Events)	y
Response Variable (Trials)	n

Number of Observations Read	8
Number of Observations Used	8
Number of Events	8
Number of Trials	193

Class Level Information

Class	Levels	Values
passagtyp	2	0 1

Criteria For Assessing Goodness Of Fit

Criterion	DF	Value	Value/DF
Deviance	4	0.0490	0.0123
Scaled Deviance	4	0.0490	0.0123
Pearson Chi-Square	4	0.0492	0.0123
Scaled Pearson X2	4	0.0492	0.0123
Log Likelihood		-29.5342	

Algorithm converged.

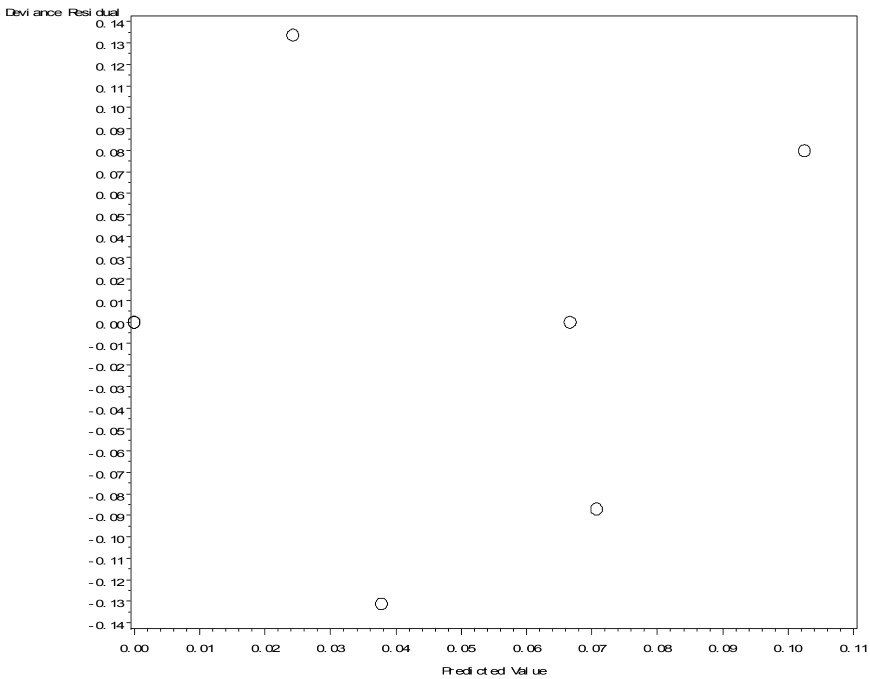
Analysis Of Parameter Estimates

Parameter			DF	Estimate	Standard Error	Wald 95% Confidence Limits		Chi-Square	Pr > ChiSq
Intercept			1	-2.1186	0.5612	-3.2184	-1.0187	14.25	0.0002
day			1	-0.0508	0.0368	-0.1229	0.0213	1.91	0.1673
passagtyp	0		1	2.4459	17184.00	-33677.6	33682.47	0.00	0.9999
passagtyp	1		0	0.0000	0.0000	0.0000	0.0000	.	.
day*passagtyp		0	1	-2.9156	17184.00	-33682.9	33677.11	0.00	0.9999

day*passagtyp	1	0	0.0000	0.0000	0.0000	0.0000	.	.
Scale		0	1.0000	0.0000	1.0000	1.0000		

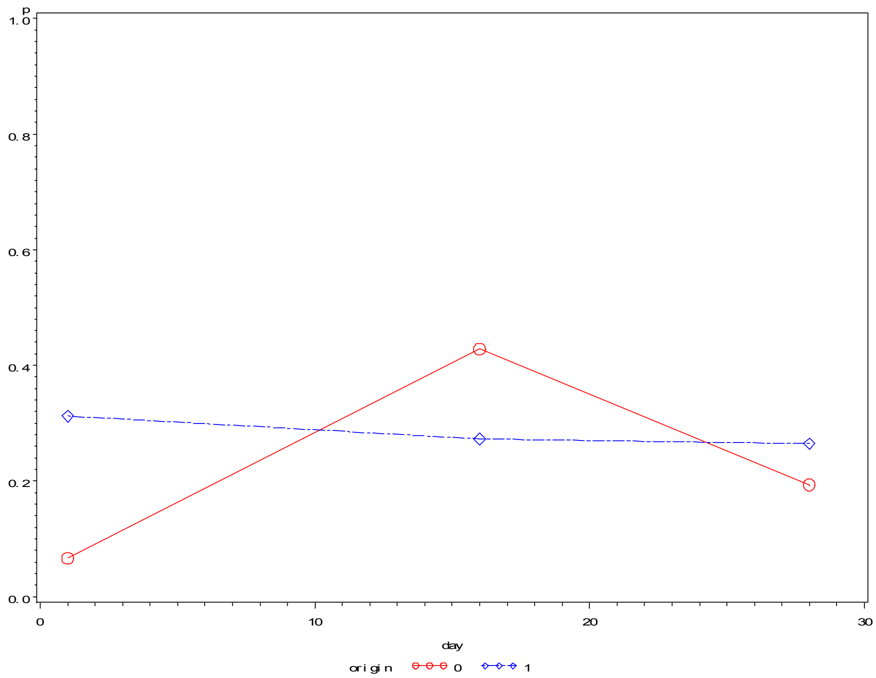
LR Statistics For Type 3 Analysis

Source	DF	Chi-Square	Pr > ChiSq
day	1	4.55	0.0329
passagtyp	1	0.02	0.8852
day*passagtyp	1	1.65	0.1993



Appendix 2.C.10. 2002 Steelhead Mortality: Barged Hatchery vs. Barged Wild

Obs	origin	day	y	n
1	0	1	1	15
2	1	1	5	16
3	0	16	6	14
4	1	16	6	22
5	0	28	6	31
6	1	28	9	34



Where 1 (diamond) = hatchery and 0 (circle) = wild

Model Information

Data Set	WORK.GB2
Distribution	Binomial
Link Function	Logit
Response Variable (Events)	y
Response Variable (Trials)	n

Number of Observations Read	6
Number of Observations Used	6
Number of Events	33
Number of Trials	132

Class Level Information

Class	Levels	Values
origin	2	0 1

Criteria For Assessing Goodness Of Fit

Criterion	DF	Value	Value/DF
Deviance	4	5.9131	1.4783
Scaled Deviance	4	4.0000	1.0000
Pearson Chi-Square	4	5.9181	1.4795
Scaled Pearson X2	4	4.0034	1.0008
Log Likelihood		-49.9909	

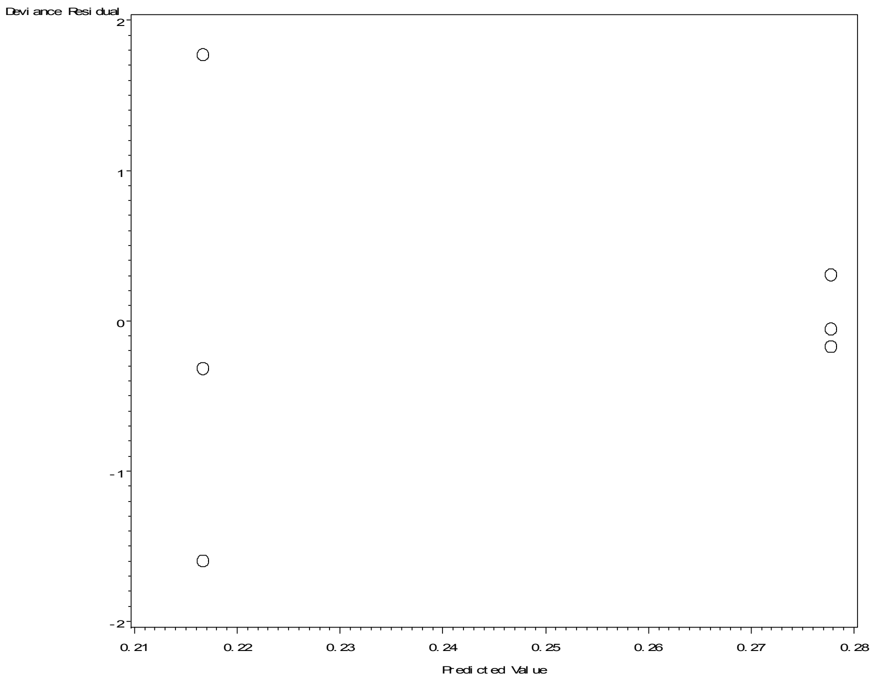
Algorithm converged.

Analysis Of Parameter Estimates

Parameter		DF	Estimate	Standard Error	Wald 95% Confidence Limits		Chi-Square	Pr > ChiSq
Intercept		1	-0.9555	0.3199	-1.5825	-0.3285	8.92	0.0028
origin	0	1	-0.3297	0.4975	-1.3048	0.6454	0.44	0.5075
origin	1	0	0.0000	0.0000	0.0000	0.0000	.	.
Scale		0	1.2158	0.0000	1.2158	1.2158		

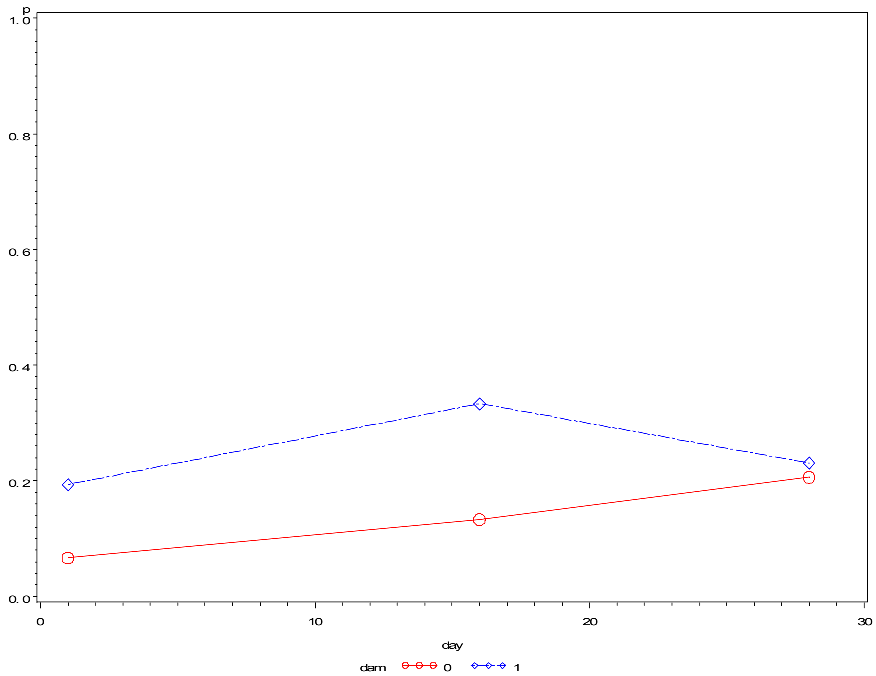
LR Statistics For Type 3 Analysis

Source	Num DF	Den DF	F Value	Pr > F	Chi-Square	Pr > ChiSq
origin	1	4	0.44	0.5416	0.44	0.5052



Appendix 2.C.11. 2002 Steelhead Mortality: Barged Fish from Lower Granite vs. Barged Fish from McNary

Obs	dam	day	y	n
1	0	1	1	15
2	1	1	6	31
3	0	16	2	15
4	1	16	12	36
5	0	28	7	34
6	1	28	15	65



Where 1 (diamond) = Lower Granite and 0 (circle) = McNary

Model Information

Data Set	WORK.GB2
Distribution	Binomial
Link Function	Logit
Response Variable (Events)	y
Response Variable (Trials)	n

Number of Observations Read	6
Number of Observations Used	6
Number of Events	43
Number of Trials	196

Class Level Information

Class	Levels	Values
dam	2	0 1

Criteria For Assessing Goodness Of Fit

Criterion	DF	Value	Value/DF
Deviance	2	1.8982	0.9491
Scaled Deviance	2	1.8982	0.9491
Pearson Chi-Square	2	1.9662	0.9831
Scaled Pearson X2	2	1.9662	0.9831
Log Likelihood		-101.0594	

Algorithm converged.

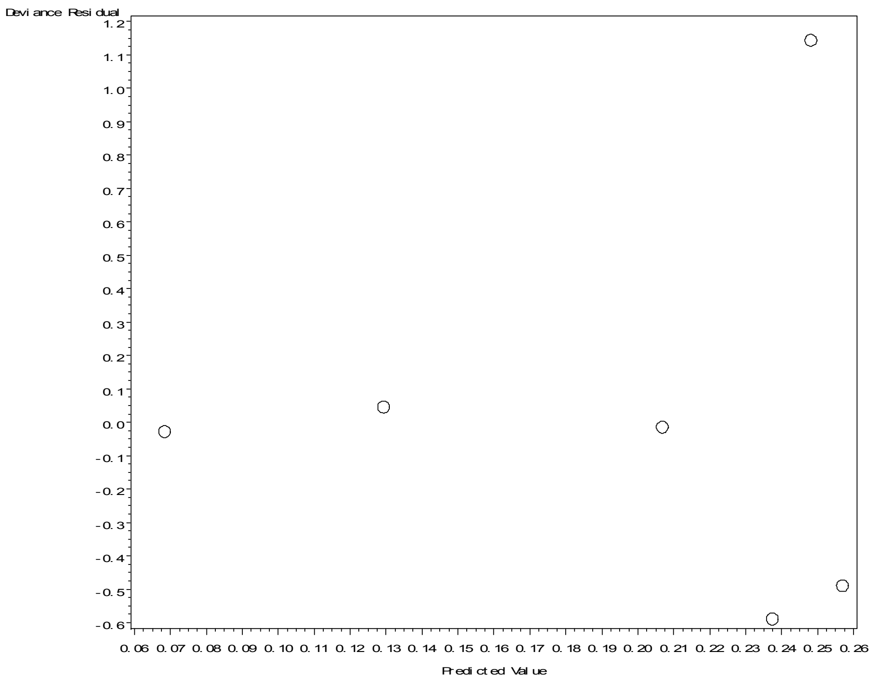
Analysis Of Parameter Estimates

Parameter		DF	Estimate	Standard Error	Wald 95% Confidence Limits		Chi-Square	Pr > ChiSq
Intercept		1	-1.1703	0.4009	-1.9561	-0.3846	8.52	0.0035
day		1	0.0039	0.0186	-0.0326	0.0404	0.04	0.8352
dam	0	1	-1.4873	1.0087	-3.4644	0.4898	2.17	0.1404
dam	1	0	0.0000	0.0000	0.0000	0.0000	.	.
day*dam	0	1	0.0430	0.0426	-0.0404	0.1265	1.02	0.3121

day*dam	1	0	0.0000	0.0000	0.0000	0.0000	.	.
Scale		0	1.0000	0.0000	1.0000	1.0000		

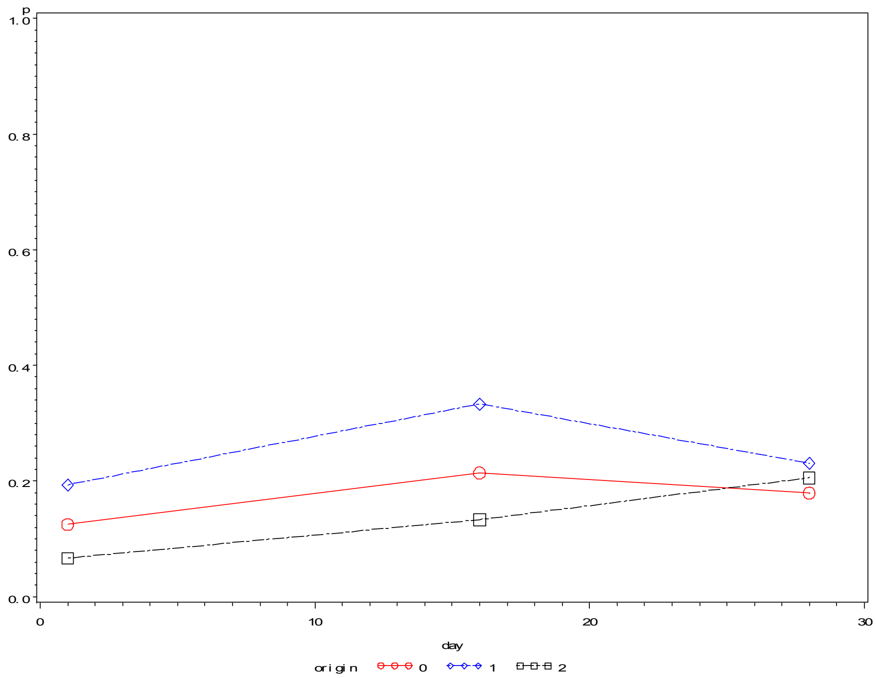
LR Statistics For Type 3 Analysis

Source	DF	Chi-Square	Pr > ChiSq
day	1	1.60	0.2062
dam	1	2.70	0.1004
day*dam	1	1.12	0.2893



Appendix 2.C.12. 2002 Steelhead Mortality: Barged (LGR) vs. Barged (McN) vs. ROR

Obs	origin	day	y	n
1	0	1	2	16
2	1	1	6	31
3	2	1	1	15
4	0	16	3	14
5	1	16	12	36
6	2	16	2	15
7	0	28	7	39
8	1	28	15	65
9	2	28	7	34



Where 1 = barged from Lower Granite (diamond), 2 = barged from McNary (square), and 0 = ROR (circle)

Model Information

Data Set	WORK.GB2
Distribution	Binomial
Link Function	Logit
Response Variable (Events)	y
Response Variable (Trials)	n

Number of Observations Read	9
Number of Observations Used	9
Number of Events	55
Number of Trials	265

Class Level Information

Class	Levels	Values
origin	3	0 1 2

Criteria For Assessing Goodness Of Fit

Criterion	DF	Value	Value/DF
Deviance	5	3.2971	0.6594
Scaled Deviance	5	3.2971	0.6594
Pearson Chi-Square	5	3.3211	0.6642
Scaled Pearson X2	5	3.3211	0.6642
Log Likelihood		-133.4153	

Algorithm converged.

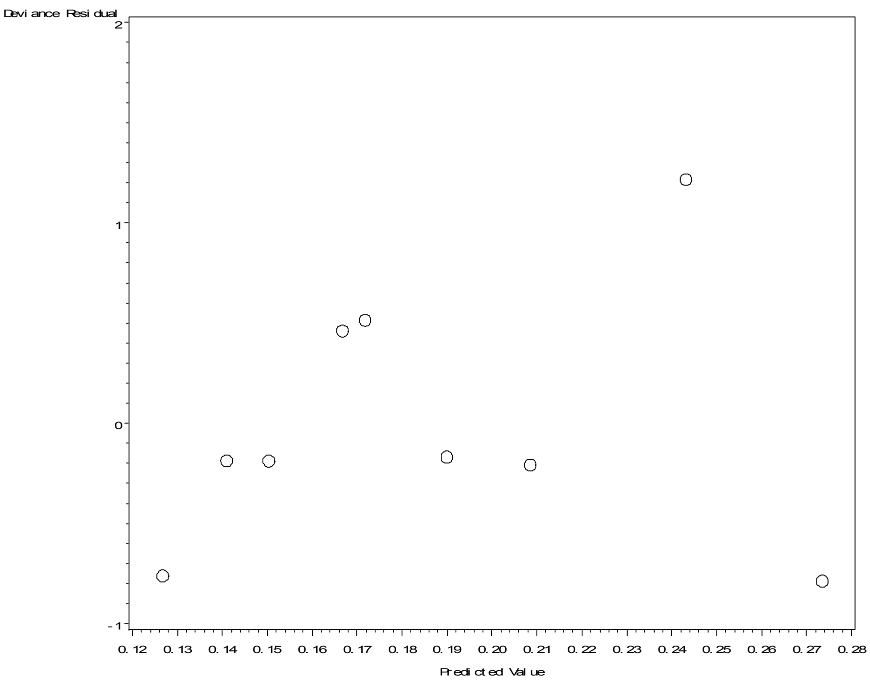
Analysis Of Parameter Estimates

Parameter		DF	Estimate	Standard Error	Wald 95% Confidence Limits		Chi-Square	Pr > ChiSq
Intercept		1	-1.9427	0.4487	-2.8222	-1.0633	18.74	<.0001
day		1	0.0132	0.0144	-0.0150	0.0415	0.84	0.3592
origin	0	1	0.1226	0.4691	-0.7967	1.0420	0.07	0.7937
origin	1	1	0.5960	0.3994	-0.1867	1.3788	2.23	0.1356

origin	2	0	0.0000	0.0000	0.0000	0.0000	.	.
Scale		0	1.0000	0.0000	1.0000	1.0000		

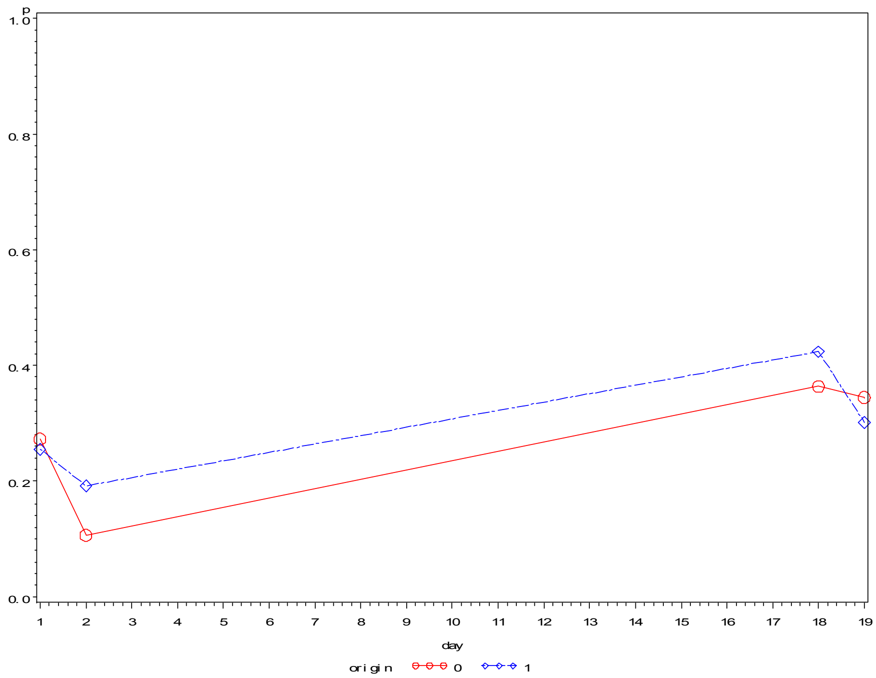
LR Statistics For Type 3 Analysis

Source	DF	Chi-Square	Pr > ChiSq
day	1	0.86	0.3532
origin	2	3.08	0.2146



Appendix 2.C.13. 2003 Steelhead Mortality: Barged Hatchery vs. Barged Wild

Obs	origin	day	y	n
1	0	1	12	44
2	1	1	12	47
3	0	2	5	47
4	1	2	9	47
5	0	18	12	33
6	1	18	25	59
7	0	19	10	29
8	1	19	19	63



Where 1 (diamond) = hatchery and 0 (circle) = wild

Model Information

Data Set	WORK.GB2
Distribution	Binomial
Link Function	Logit
Response Variable (Events)	y
Response Variable (Trials)	n

Number of Observations Read	8
Number of Observations Used	8
Number of Events	104
Number of Trials	369

Class Level Information

Class	Levels	Values
origin	2	0 1

Criteria For Assessing Goodness Of Fit

Criterion	DF	Value	Value/DF
Deviance	5	7.7906	1.5581
Scaled Deviance	5	5.0000	1.0000
Pearson Chi-Square	5	7.4996	1.4999
Scaled Pearson X2	5	4.8132	0.9626
Log Likelihood		-137.5678	

Algorithm converged.

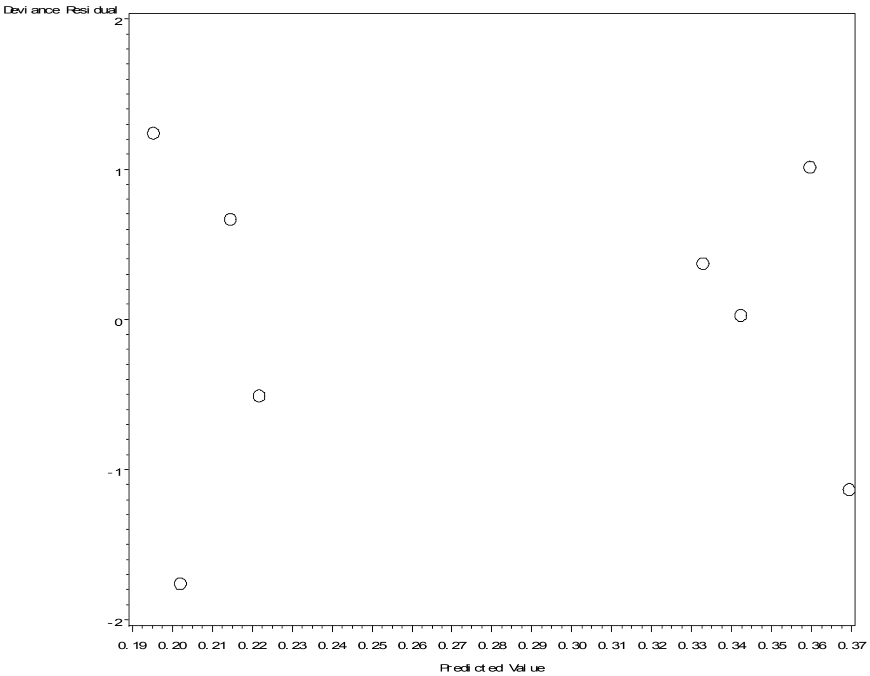
Analysis Of Parameter Estimates

Parameter		DF	Estimate	Standard Error	Wald 95% Confidence Limits		Chi-Square	Pr > ChiSq
Intercept		1	-1.3401	0.2875	-1.9036	-0.7766	21.73	<.0001
day		1	0.0424	0.0176	0.0078	0.0769	5.78	0.0162
origin	0	1	-0.1183	0.3036	-0.7133	0.4767	0.15	0.6968
origin	1	0	0.0000	0.0000	0.0000	0.0000	.	.

Scale 0 1.2482 0.0000 1.2482 1.2482

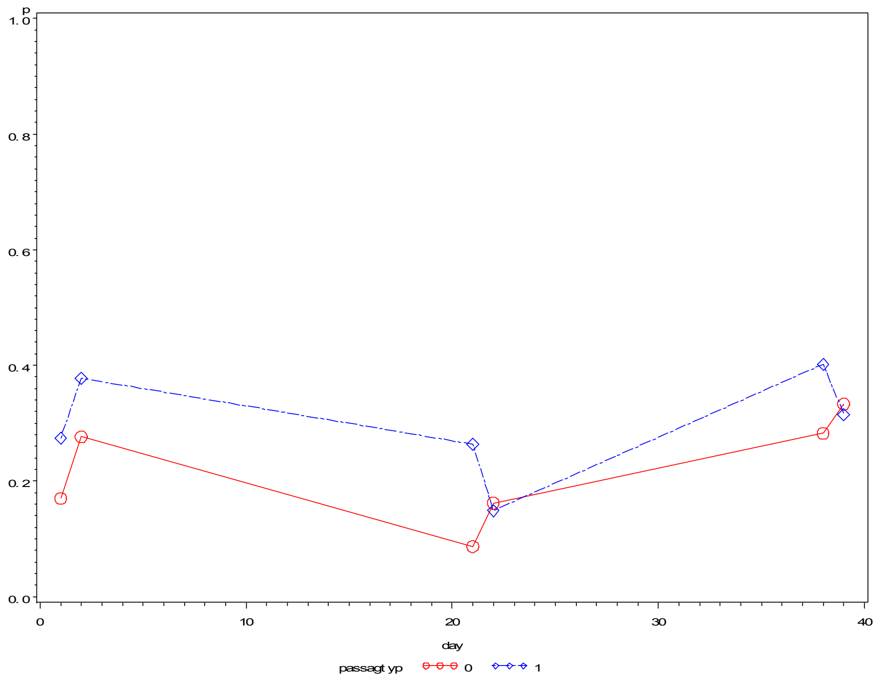
LR Statistics For Type 3 Analysis

Source	Num DF	Den DF	F Value	Pr > F	Chi-Square	Pr > ChiSq
day	1	5	5.93	0.0590	5.93	0.0149
origin	1	5	0.15	0.7124	0.15	0.6963



Appendix 2.C.14. 2003 Steelhead Mortality: Barged vs. ROR

Obs	passagtyp	day	y	n
1	0	1	8	47
2	1	1	25	91
3	0	2	13	47
4	1	2	34	90
5	0	21	4	46
6	1	21	24	91
7	0	22	6	37
8	1	22	14	94
9	0	38	13	46
10	1	38	37	92
11	0	39	15	45
12	1	39	29	92



Where 1 (diamond) = barged and 0 (circle) = ROR

Model Information

Data Set	WORK.GB2
Distribution	Binomial
Link Function	Logit
Response Variable (Events)	y
Response Variable (Trials)	n

Number of Observations Read	12
Number of Observations Used	12
Number of Events	222
Number of Trials	818

Class Level Information

Class	Levels	Values
passagtyp	2	0 1

Criteria For Assessing Goodness Of Fit

Criterion	DF	Value	Value/DF
Deviance	10	31.5698	3.1570
Scaled Deviance	10	10.0000	1.0000
Pearson Chi-Square	10	29.8590	2.9859
Scaled Pearson X2	10	9.4581	0.9458
Log Likelihood		-150.6267	

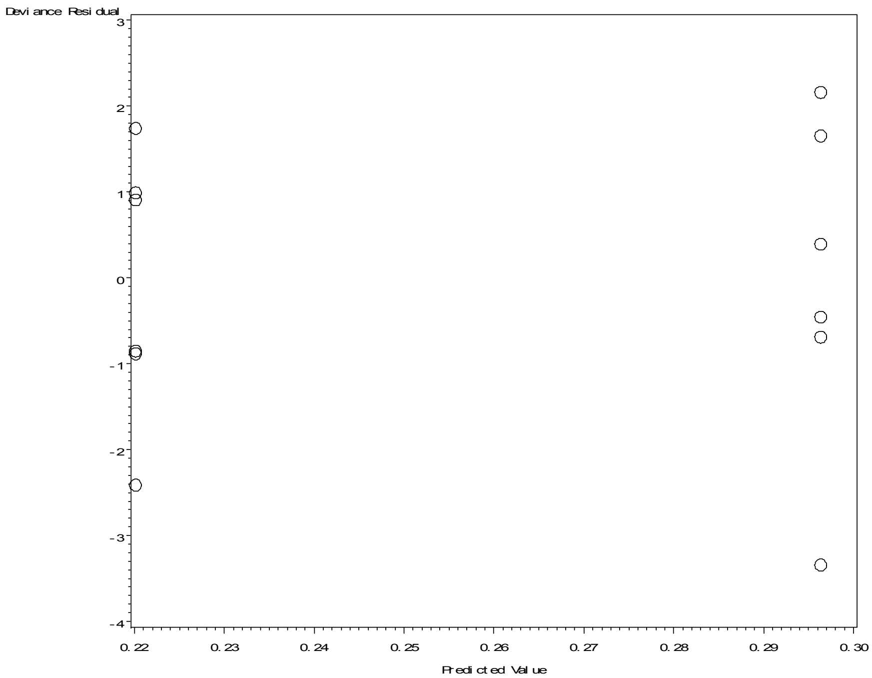
Algorithm converged.

Analysis Of Parameter Estimates

Parameter		DF	Estimate	Standard Error	Wald 95% Confidence Limits		Chi-Square	Pr > ChiSq
Intercept		1	-0.8647	0.1659	-1.1898	-0.5395	27.16	<.0001
passagtyp	0	1	-0.4001	0.3101	-1.0078	0.2076	1.67	0.1969
passagtyp	1	0	0.0000	0.0000	0.0000	0.0000	.	.
Scale		0	1.7768	0.0000	1.7768	1.7768		

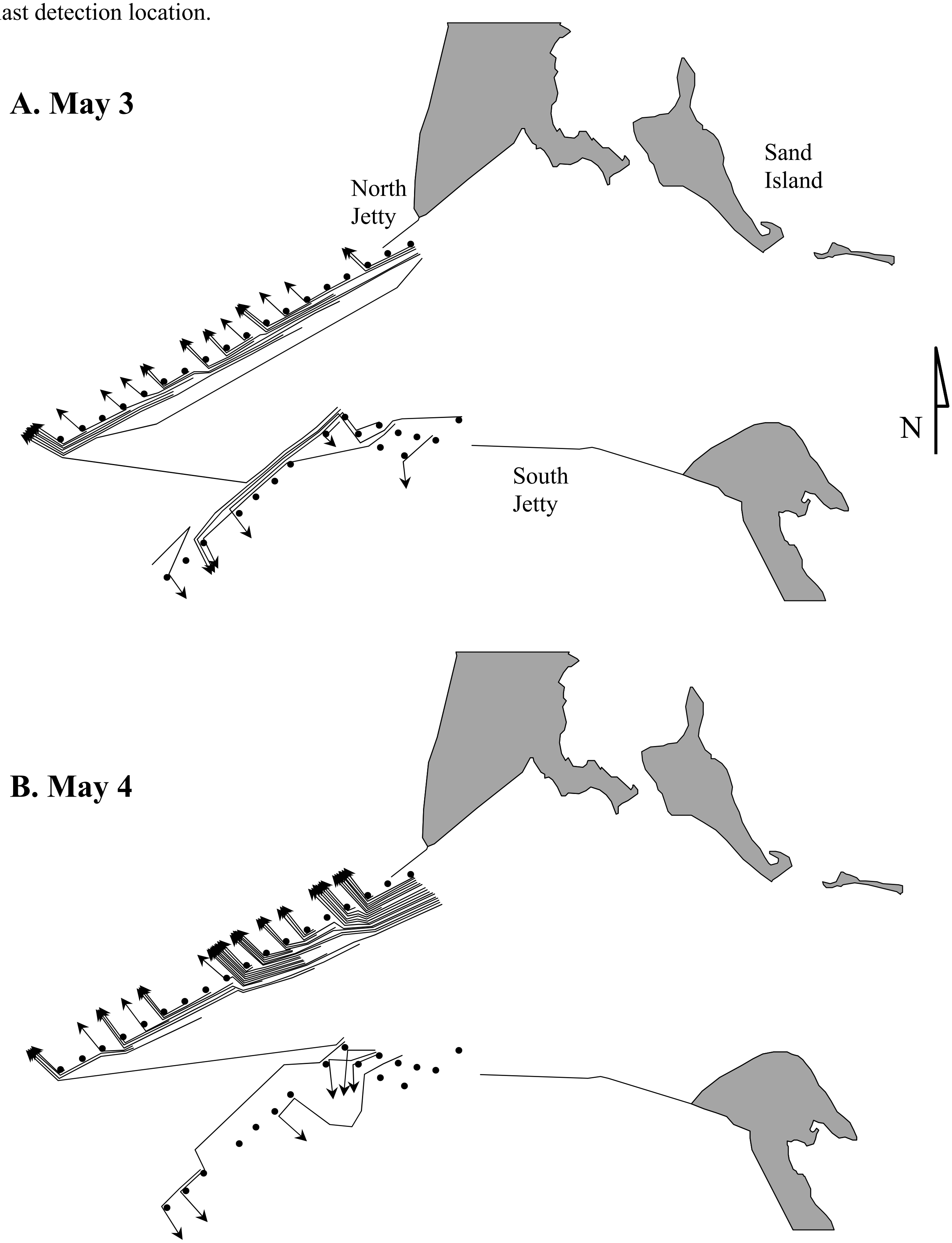
LR Statistics For Type 3 Analysis

Source	Num DF	Den DF	F Value	Pr > F	Chi-Square	Pr > ChiSq
passagtyp	1	10	1.72	0.2194	1.72	0.1901

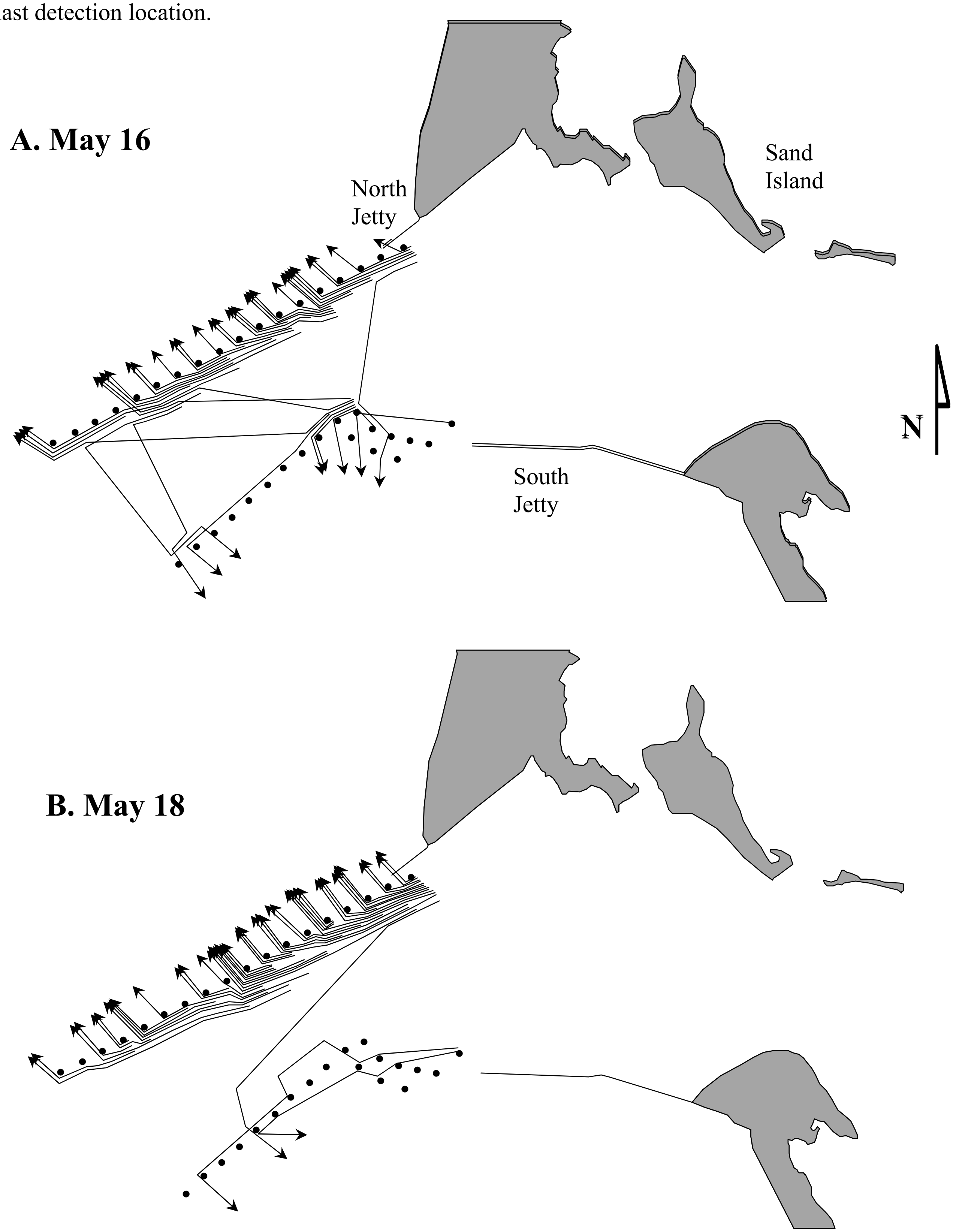


Appendix 3

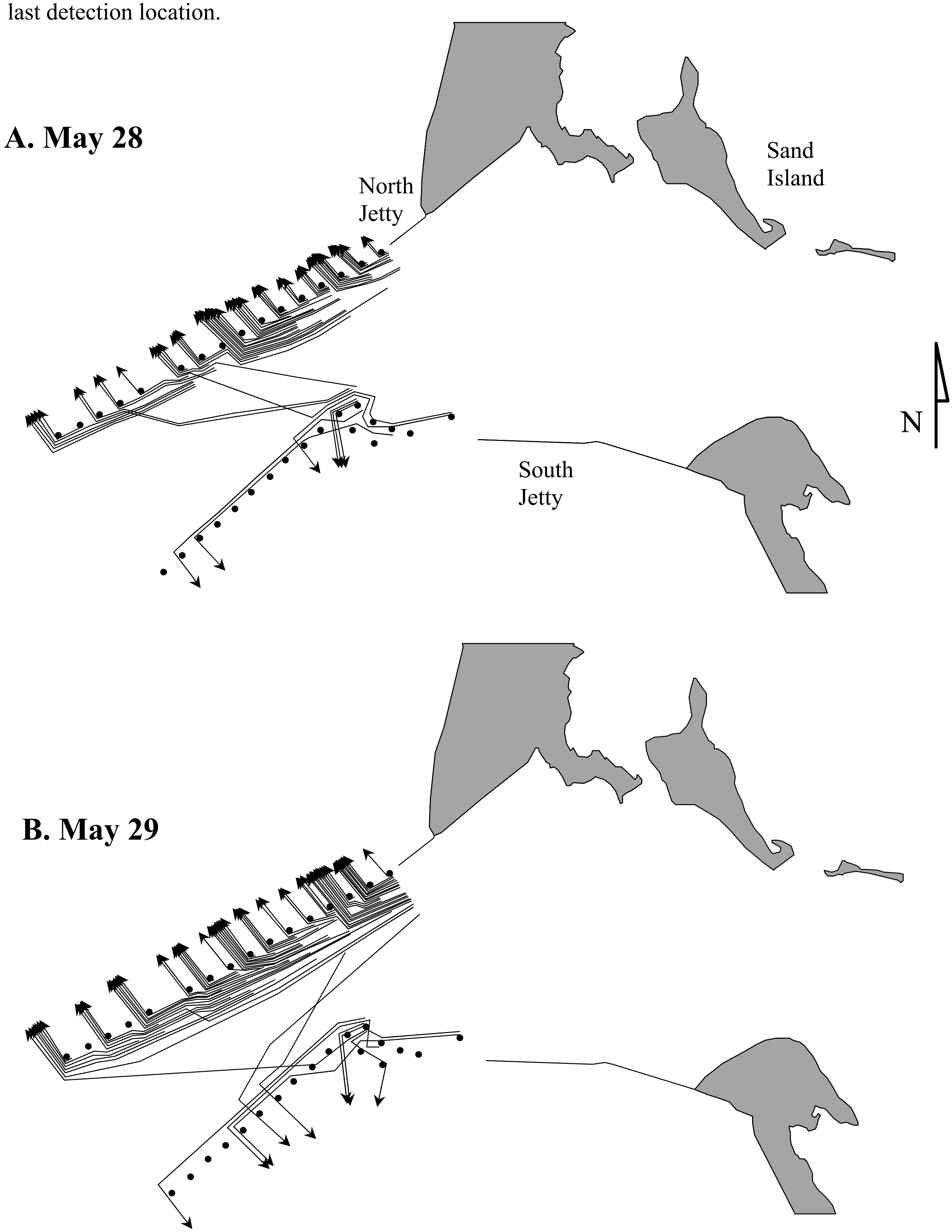
Appendix 3, Figure 1. The possible ocean migration direction of acoustically tagged spring/summer Chinook released on (A) May 3 and (B) May 4, 2004. Dots show the location of individual buoy-receiver systems, lines indicate consecutive detections, and arrows signify the last detection location.



Appendix 3, Figure 2. The possible ocean migration direction of acoustically tagged spring/summer Chinook released on (A) May 16 and (B) May 18, 2004. Dots show the location of individual buoy-receiver systems, lines indicate consecutive detections, and arrows signify the last detection location.



Appendix 3, Figure 3. The possible ocean migration direction of acoustically tagged spring/summer Chinook released on (A) May 28 and (B) May 29, 2004. Dots show the location of individual buoy-receiver systems, lines indicate consecutive detections, and arrows signify the last detection location.



Appendix 4

Appendix 4, Table 1. The number of individual steelhead detected in 2002 for the three large-scale migration patterns in the estuary for both types of fish in each release. The number of those fish that were subsequently detected on the Ocean Array and the corresponding survival from the Astoria Bridge to the Ocean Array is shown. The pooled row includes only the second and third releases because it was not known that fish were using the middle channel in the first release. Note that the middle channel bouy-receiver system was not present during the first release.

		# of individual fish detected			# of fish detected at bridge that were subsequently detected on ocean array			% survival, not adjusted for efficiency		
		ROR	BRG		ROR	BRG		ROR	BRG	Types pooled
Release 1	OR Channel	11	14	OR Channel	10	7	OR Channel	90.9	50.0	68.0
	WA Channel	9	13	WA Channel	5	9	WA Channel	55.6	69.2	63.6
	Mid Channel	-	-	Mid Channel	-	-	Mid Channel	-	-	-
		ROR	BRG		ROR	BRG		ROR	BRG	Types pooled
Release 2	OR Channel	15	20	OR Channel	11	15	OR Channel	73.3	75.0	74.3
	WA Channel	12	8	WA Channel	8	4	WA Channel	66.7	50.0	60.0
	Mid Channel	5	3	Mid Channel	5	2	Mid Channel	100.0	66.7	87.5
		ROR	BRG		ROR	BRG		ROR	BRG	Types pooled
Release 3	OR Channel	5	6	OR Channel	2	4	OR Channel	40.0	66.7	54.5
	WA Channel	12	11	WA Channel	4	5	WA Channel	33.3	45.5	39.1
	Mid Channel	6	8	Mid Channel	4	6	Mid Channel	66.7	75.0	71.4
		ROR	BRG		ROR	BRG		ROR	BRG	Types pooled
Pooled	OR Channel	20	26	OR Channel	13	19	OR Channel	65.0	73.1	69.6
Releases 2 and 3	WA Channel	24	19	WA Channel	12	9	WA Channel	50.0	47.4	48.8
	Mid Channel	11	11	Mid Channel	9	8	Mid Channel	81.8	72.7	77.3

Appendix 4, Table 2. The number of individual steelhead detected in 2003 for the three large-scale migration patterns in the estuary for both types of fish in each release. The number of those fish that were subsequently detected on the Ocean Array and the corresponding survival from the Astoria Bridge to the Ocean Array is shown. Pooled types are included for each release and for pooled releases.

Release Date	# of individual fish detected			# of fish detected at bridge that were subsequently detected on ocean array			% survival, not adjusted for efficiency			
		BRG	ROR		BRG	ROR		BRG	ROR	Types Pooled
5/2/03 AM	WA Channel	2	14	WA Channel	1	8	WA Channel	50%	57%	56%
	Mid Channel	1	9	Mid Channel	1	6	Mid Channel	100%	67%	70%
	OR Channel	4	10	OR Channel	1	7	OR Channel	25%	70%	57%
		BRG	ROR		BRG	ROR		BRG	ROR	Types Pooled
5/2/03 PM	WA Channel	16	9	WA Channel	8	7	WA Channel	50%	78%	60%
	Mid Channel	12	8	Mid Channel	6	4	Mid Channel	50%	50%	50%
	OR Channel	17	7	OR Channel	15	3	OR Channel	88%	43%	75%
		BRG	ROR		BRG	ROR		BRG	ROR	Types Pooled
5/22/2003	WA Channel	12	11	WA Channel	7	6	WA Channel	58%	55%	57%
	Mid Channel	6	5	Mid Channel	4	4	Mid Channel	67%	80%	73%
	OR Channel	19	3	OR Channel	17	3	OR Channel	89%	100%	91%
		BRG	ROR		BRG	ROR		BRG	ROR	Types Pooled
5/24/2003	WA Channel	24	4	WA Channel	16	1	WA Channel	67%	25%	61%
	Mid Channel	15	2	Mid Channel	13	1	Mid Channel	87%	50%	82%
	OR Channel	44	6	OR Channel	36	4	OR Channel	82%	67%	80%
		BRG	ROR		BRG	ROR		BRG	ROR	Types Pooled
6/6/2003	WA Channel	13	5	WA Channel	7	1	WA Channel	54%	20%	44%
	Mid Channel	7	9	Mid Channel	4	5	Mid Channel	57%	56%	56%
	OR Channel	31	14	OR Channel	25	6	OR Channel	81%	43%	69%
		BRG	ROR		BRG	ROR		BRG	ROR	Types Pooled
6/8/2003	WA Channel	18	5	WA Channel	10	2	WA Channel	56%	40%	52%
	Mid Channel	9	2	Mid Channel	7	1	Mid Channel	78%	50%	73%
	OR Channel	21	4	OR Channel	7	3	OR Channel	33%	75%	40%
		BRG	ROR		BRG	ROR		BRG	ROR	Types Pooled
Pooled	WA Channel	85	48	WA Channel	49	25	WA Channel	58%	52%	56%
Releases	Mid Channel	50	35	Mid Channel	35	21	Mid Channel	70%	60%	66%
	OR Channel	136	44	OR Channel	101	26	OR Channel	74%	59%	71%